SECRET

HOME OFFICE DISCREET NEW COVER 19 AUG 82 (K)

FILE BEGINS	ENDS	FILE NUMBER
FILE TITLE		SAN 62 0019/0007/001/

FILE TITLE: COMMUNICATIO[NS]

EFFECT OF ELECTRO-MAGNETIC PULSE

W 1895

FILE NUMBER: SAN 62 19/7/1

DISPOSAL DIRECTIONS		SIGNATURE	DATE
DESTROY AFTER	YRS.		
PRESERVE			
CONSIDER AT 1st/2nd REVIEW			

When papers require action by Noter, the word NOTE should be inserted in the box

1.
2.
3.

CLOSED INDEX HEADINGS CLOSED

HO 338/146

SECRET

SEND TO	DATE	SEND TO	DATE	SEND TO	DATE
P.A.					

SECRET

HOF000480550

32628—6-9-73 XBD 1713

Appendix A

Agenda

DASA Symposium on Small Boy Event
Programs 2, 6 and 7

East Building Lecture Room, Bldg 2
National Bureau of Standards
Washington, D.C.

0900 - 1600

13 - 14 November 1962

CDR W. W. Ennis, USN, Chairman
P. Haas, DOFL, Co-Chairman
Dr. C. A. Blank, DASA, Assistant

Welcome ....Lt.Col. R. W. McEvoy, USA
Introductory Remarks ....General R. H. Booth, USA
Administrative Remarks ....P. Haas

Session I - Environmental Measurements

Dr. L. Wouters, Chairman

Time		Project Title	Project Officer
0915 - 0945	2.1	Gamma Dose Rate	P. A. Caldwell
0945 - 1000	2.3	Neutron Flux Measurements	J. H. McNeilly
1000 - 1015	2.4	Integrated Gamma Dose	R.F. Benck
1015 - 1045	2.2	Neutron Dose Rate	Dr. S. Kronenberg
	6.4	Semirad Initial Gamma Flux Measurements	Dr. S. Kronenberg
1045 - 1100		Coffee Break	
1100 - 1115	6.7	Soil Conductivity Measurements	R. A. Black
1115 - 1130	6.11	Air Conductivity	Dr. M. Jones
1130 - 1200	6.12	U.K. Measurements	Dr. E. D. Draycott
1200 - 1330		Lunch	
1330 - 1350	7.1.4	Gamma Environment	Dr. A. Odell
1350 - 1400	45.9	Neutron and Gamma Measurements	G. Hansen
1400 - 1430	22.1	EG & G Gamma Measurements	M. Knapp

Session II - Magnetic Field Measurements

P. Haas, Chairman

Time		Project Title	Project Officer
1430 - 1500	6.2	Magnetic Loop Measurements	F. Wiminetz
1500 - 1530	6.3	Inherent Magnetic Field Measurements	T. D. Hanscome
1530 - 1545	7.8.1	VLF Loop	Mr. Salton

Wednesday 14th November 1962

Session III - Pragmatic Measurements

Capt. W. Henderson, Chairman

0900 - 0945	6.5	Earth Current Measurements	T. Flanagan F. Schwartz
0945 - 1015	6.6	Cable Loop Measurements	W. Green
1015 - 1045	7.1	Instrumental Measurements	F. Norton R. Buies
1045 - 1100		Coffee Break	
1100 - 1115	7.5	Response of Electric Power Systems	D. E. Dinger
1115 - 1130	45.10	Electromagnetic Radiation Vulnerability	F. J. Weibell
	6.2(c)	Magnetic Measurements	D. J. Garrard
1200 -1300		Lunch	

Session IV - Electric Field Measurements

Dr. J. Malik, Chairman

1300 - 1330	6.1	Electric Field Measurements	W. Nesbitt
1330 - 1345	6.8	Earth's Static Field Measurements	A. Whitson
1345 - 1415	6.9	Correlation of Present and Previous Electric Field Measurements	H. Reno
1415 - 1445	6.12	AWRE Measurements	S.D. Abercrombie
1445 - 1500	7.16	Airborne Electric Field Measurements	LCDR K. Butler
1500 - 1515	45.10	Electromagnetic Radiation Vulnerability	R. Parker

Session V - Panel Discussion and Free-For- All

Dr. C. Longmire, Chairman

1515 - 1615	T	Theoretical Consideration and Comments on the Data	

S E C R E T

Discreet

Ref: XY/398/01

NWLC/P(62)12

JOWOG-6
D.A.S.A. Symposium on Small Boy Event
Programmes 2, 6 & 7

Introduction

Through U.S./U.K. Joint Working Group No.6, we were invited to participate in a Symposium held at the National Bureau of Standards, Washington, on 13th and 14th November, 1962. At this symposium all available data were presented on the following experimental programmes of Small Boy:-

Programme 2 - Measurement of Neutron and Gamma Doses and Dose Rates.

Programme 6 - Electric and Magnetic Field Measurements, Air and Soil Conductivity.

Programme 7 - Electromagnetic Flash Target Response Measurements.

Items included in these programmes are listed in NWLC/P(62)7.

The remainder of the 88 Items of the Small Boy programme were excluded from this Symposium. The effects of nuclear radiation on electronics had been covered in a recent DASA TREE panel meeting.

A.W.R.E. were invited to describe the results of their electric field and air conductivity measurements, and in the course of the symposium the Ministry of Aviation representative was asked to describe his magnetic measurements. The programme of the Symposium, with subjects of individual contributions, is given in the Agenda at Appendix 'A'.

Nuclear Radiation Data

A considerable amount of raw data on the time dependence of the neutrons and gamma radiation, as measured in a variety of ways, was presented by DOFL, NDL, SRDL, EG & G and Northrop-Ventura. Total dose measurements were also reported. The overall impression was gained that the data from different sources only agreed to within an order of magnitude at this stage, and that there was yet much work to be done in sorting out the discrepancies, mainly due to instrumentation. Nevertheless the data from Small Boy, although not wholly consistent, represented a considerable increase in our knowledge.

Air Conductivity

As an important part of the attempt to develop a soundly based theoretical approach to the origins and propagation of radio-flash, several measurements of air and soil conductivity as a function of time were carried out by different agencies. These included air measurements by Magnetohydrodynamics Corporation under contract to U.S. Air Force Special Weapons Center and by A.W.R.E., and soil conductivity measurements by the U.S. Geological Survey. The A.W.R.E. measurements were of high time resolution and should represent an important contribution to basic knowledge.

Magnetic Field Measurements

The principal effort was that by DOFL, who measured the magnetic field by integrating the output from small pick-up loops at a number of sites. Despite overloading caused by a fairly late change in the nuclear device used for the test, their measurements were largely successful, and included for the first time measurements 100 ft. below ground. Notes of many of their curves have been made. The Ministry of Aviation contribution, which included the measurement of the peak field pick-up by search coils inside 8 aluminium containers placed at ground level, was associated with this work.

S E C R E T

It was reported that the large programme of direct measurements of the magnetic field by Hughes Aircraft Co. had proved abortive.

Electric Field Measurements

The main U.S. effort on electric field measurements was by Boeing Airplane Company. The considerable amount of raw data obtained was reported but will require a considerable degree of interpretation, in view of the nature of the equipment used. The largely successful corresponding measurements by A.W.R.E. were also reported, as were several unsuccessful U.S. experiments.

Effects on Electronic Systems

One of the more expensive programmes at Small Boy, was an elaborate investigation of the currents induced in buried multi-core cable systems. This was performed by the Bell Telephone Laboratories, by Sandia Corporation, by Allied Research Associates for A.F.S.W.C., and others. Measurements were made at a number of places of the wave-form of the induced currents, and peak current indicators were widely distributed. The cables laid included a number of both bare and insulated radial cables, and both large and small cable loops. The aim was to include both basic measurements, and also to give some help in the estimation of the hazard to a particular type of American I.C.B.M. underground installation. Most of the cables were buried about 3ft. below the surface. Although currents up to several thousands of amps. were recorded the currents ranging into tens of thousands of amps which had been anticipated were not found. To this extent the experiments were somewhat reassuring, but it must be remembered that the shot was a small one, and the scaling laws to yields of interest in this application are still open to a moderate degree of doubt. It seems reasonable to expect that some American agencies will wish for a further investigation involving a much higher yield burst.

Results were also reported of measurements at a second shot - Johnny Boy - at which a cable loop completely encircled ground zero. These latter results were limited by instrumental failures, and did no more than indicate that peak valves were consistent with those found at Small Boy.

Reports

The whole Symposium was recorded, and copies of graphs and illustrations were handed in. D.A.S.A. intend to produce a full Symposium record in the next few weeks and U.K. have been promised copies of what should be a most valuable document. As most of the mass of detail was presented in the form of slides and epidiascope projections, note-taking by U.K. participants was extensive but scrappy. Briefings are being arranged for U.K. JOWOG-6 members and others interested in further details.

Conclusions

It is evident that while a surprising number of experiments failed completely, a considerable amount of information has been added to our knowledge of radio-flash and its effects. Nevertheless it is equally evident that this information has not yet been fully digested in the U.S., and it appears likely that the Small Boy event, while considerably advancing our knowledge, will have raised as many questions as it has answered.

There is clear evidence that the fields, even from a very nearly perfectly symmetrical explosion, vary considerably with azimuth, and that the magnitudes of the fields do not at all decrease monotonically with increasing distance.

Some Observations of Electro Magnetic Flash Damage resulting from Nuclear Explosions

The information presented below has been acquired incidentally during nuclear weapon tests, when instrumentation has been designed to record other effects, and is therefore mainly empirical. Awareness has nevertheless grown that electro-magnetic radiation can cause severe damage or operational disruption in all kinds of electrical systems.

Electro-magnetic radiation from a weapon encompasses a very broad band of radio frequencies and can induce large voltages, and currents in conductors and circuits, even when they are remote from the explosion. Complex control circuits and communication and power lines represent large antennae in which disturbing signals are induced by the radiation and are particularly vulnerable, and damage can occur many miles from the explosion.

The examples quoted here are limited to observations made by the personnel of Edgerton, Germeshausen and Grier during test series from 1951 to 1958. The charts summarize damage under the categories of

1) Damage to Signals Systems

2) Damage to Power Systems

3) Damage to Systems using Earthing and Screening protection.

4) Miscellaneous Damage.

Examination of the data shows that while, in general, damage increases with the yield of the device, and air and balloon shots are more damaging than tower or underground shots, it is not possible to correlate effects directly with either yield, type of device or height of burst. Moreover, while a typical pattern of damage can be observed where extensive cable lines exist, so that probable sites of damage can be indicated, the induced voltages nevertheless tend to build up in an unpredictable manner, similar to a lightning strike. An example of this is the violent explosion at a conduit entrance 13 miles from G.Z. with no recorded damage to the intermediate signals system.

As would be expected, the lighter conductors used in signals systems showed more serious damage than power lines, but the effect was transmitted to greater distances by the heavier cables, causing circuit breakers to trip at distances of over 30 miles from G.Z. Damage to equipment at intermediate stations could be catastrophic in either case.

A point not apparent from the damage summaries should be noted in respect of telephone communications. The contractors state that it was found necessary to remove the commercial type carbon blocks for voltage surge protection, since these were found in most cases to fuse or weld together, short-circuiting the signal. Jumpers were substituted in their place.

Protection against anticipated effects was employed only in the case of certain equipment, in which extensive earthing and screening devices were used, and these were to a large extent effective. The danger to electronic equipment, however, is shown by the random malfunctioning of the counting unit, controlling timing of camera shutters. This effect was subsequently repeated by an experimentally induced electric field, confirming the cause of failure. It is generally clear that increased sensitivity of equipment implies increased vulnerability to electro-magnetic effects, and that protection of oscilloscopes is necessary to avoid obliteration ('blooming') or distortion of the signal.

Actual measurement of an induced voltage is shown in only one example, where approximately 3250 volts was recorded by a galvanometer, protected by a 10,000 volt air gap, inserted in an unconnected $5\frac{1}{2}$ miles length (paired) of timing signal lines, running from within $\frac{1}{2}$ mile of G.Z.

Damage to Signals Systems

Typical

Distance from G.Z.

1500'	½ mile	2½ miles	5½ miles	8 miles	17 miles
Connection Box Invariably blown or fused	Timing Distribution Station Meters, relays burned out. Terminal strips melted	Timing stations Meters, potentiometers, relays damaged or destroyed. Pins melted off relays, meters burned out.			Control Point Meters, Relays burned

Cables (1500' to ½ mile): Cables fused. Insulation breakdown

Cables (½ mile to 2½ miles): Cables fused. Insulation break-down

Cables (2½ miles to 5½ miles): Cable insulation damage

Cables (8 miles to 17 miles): Cable insulation damage

Examples

Yield	Type and Height of Burst	
Over-nominal	Tower 700'	2 miles Timing Stns. 6 meters and potentiometers, 3 relays destroyed. 17 miles Control Pt. 2 meters destroyed
Sub-nominal nominal and over-nominal	Series of balloon shots No height given	1500' Connection box for balloon signal cable destroyed. ½ mile Timing Distn.Stn. Insulation destroyed Conductors fused together. 2 miles Timing Stns. Insulation breakdown on cables.
Nominal	Tower 500'	3500' Timing Distn. Stn. Random malfunction of indicators
Nominal	Air 524'	2½ miles Timing station Random malfunction of indicators
Sub-nominal	Series of Balloon shots No height given	1500' Connection box for balloon signal cable destroyed ½ mile Timing Distn.Stn. Cables to sub-station and Timing stations damaged.
Not given	Series of Tower shots No height given	1500' Suppression box Capacitors destroyed ½ mile Timing Distn. Stn. Relays burnt out
Nominal	Air 6020'	3 miles Telephone relay stn. Carbon contacts fused. Conductors fused in cables on far side.
Over-nominal	Tower 300'	13 miles Control point Explosion at conduit entrance. Lead sheathing evaporated
Not given	Underground Series	about 1 mile Signal cables fused in underground tunnel

Damage to Power Systems

Typical

Distance from G.Z

1000' Portable sub-station	3000' Power distribution Station	3 miles Power distribution station	12 miles Control Point	30 miles Power station
Fuses blown, arcing across insulation.	Fuses, blown, arcing across insulation. Short-circuiting across transformer windings. Arcing to transformer case.	Oil circuit breakers tripped		Oil circuit breakers tripped
Pinhole damage to cable insulation, near to sub-station		Cable insulation damage		

Examples

Yield	Type and Height of Burst	
Over-nominal	Tower 300'	½ mile. Experimental cages; ½ mile radius from G.2. Cables buried 18" depth. All destroyed by pinholes in insulation.
Nominal	Tower 300'	1000' Sub-station and power stations; 6' underground. Cable between stations destroyed. Transformer primary fused, and arced to core.
Not given	Underground series	about 1 mile, underground tunnel. Insulation damage, by charring, to power cables.

Damage to certain Systems in which extensive Earthing and Screening was used

Yield	Type and Height of Burst	Distance from G.Z.
Not given	Series of Tower and balloon shots	Station at 3000 ' Resistors destroyed
Over nominal	Tower 500'	Station at 3000' Oscilloscope exploded
Nominal	Tower 300'	1000' Station 6' underground. Transformer primary fused, arcing to core. 2 miles Photographic recording station. Electronic counting unit. Malfunctioned in random manner.
Not given	Series of Tower and balloon shots	Station at 3000' Pins of rectifiers in oscilloscopes burned off. Glass envelope shattered in most cases. 6 x 4 type rectifiers.
Nominal	Tower 500'	11 miles Oscilloscope with photo-multiplier, for light analysis (unscreened) "Ball-of-yarn" distortion of trace.
Not given	Underground Series	about 1 mile, underground tunnel Breakdown of cable insulation, burned spots for 50 feet.

Miscellaneous Damage

Yield	Type and Height of Burst	Distance from G.Z.
Nominal	Balloon 1500'	3 miles 1000 feet length of 4-conductor, 6000 V cable, on reel, unconnected. 600-V cable Pinhole damage to insulation along complete length.
Nominal	Tower 300'	3000' 1000 feet length of single-pair wire, on surface, unconnected. Draped over station building. Burning at end touching metal plug in wall, 3" burning on wall, melting of wires for $\frac{1}{2}$".
Nominal	Balloon 1500'	$5\frac{1}{2}$ miles Galvanometer recording of 3250 volts induced in timing signal lines, unconnected, running from timing distribution stati n at $\frac{1}{2}$ mile from G.Z.

XY/306/01

Minutes of a Meeting held in Room 208, Horseferry House, Dean Ryle Street, S.W.1, at 10.30 a.m. on 20th October, 1964.

Present		Representing
Mr. H.A. Sargeaunt	In the Chair	Sc. Adv., Home Office.
Mr. J. Brooker		Home Office, Comm. Branch
Mr. R.E. Glaysher		" "
Mr. N. Morley		" "
Mr. R. Watson		" "
Mr. R. Firth		" "G" Divn.
Mr. J. Miles		" S.A.B.
Mr. F.H. Pavry		" "
Mr. G.R. Stanbury		" "
Mr. E. Leader-Williams		" "
Mr. N.F. Law		" Warn. & Mon. Branch
Mr. J. Gelly		" " " "
Mr. G. Potter		" " " "
Sir W.H. Merton		Insp.Gen. of C.D.
Mr. C.E.C. Hurst		Ministry of Public Buildings and Works
Mr. C.W. Mott		C.E.G.B./H.Q.
Mr. E.J. Whitcher		London Elec. Board.
Mr. T. Kilvington		G.P.O./E.D.
Mr. K. Ford		G.P.O./I.T.D. PB.
Mr. R.H. Franklin		G.P.O./E.D. L.M.O.
Col. T.W. Armour		A.W.R.E.
Gp.Capt. P.M. Chettle		M.O.A., A.D./A.W.D.2.
Mr. D.J. Garrard		" A.W.D.2 (Effects)
Mr. T.S. Popham		M.O.D./Ord. Board
Mrs. M.E. Wilkie	Secretary	M.O.A., A.W.D.2.

1. Mr. Sargeaunt introduced the speakers from the Ministry of Aviation and the Ordnance Board, and said that the meeting was specifically concerned with the hazard from electromagnetic flash to electrical installations and equipments of all kinds. Group Captain Chettle said that it was necessary to correlate the damage radius for EM flash with those of the more obvious hazards from a nuclear burst, in order to assess its significance at any given position. A brief summary of the main effects, including nuclear radiation, would be presented, proceeding to EM flash phenomena. Thence the meeting should proceed to its main purpose, which was to obtain the views of users of equipments and installations threatened by this hazard. A knowledge of the problems in the communications and power transmission fields was necessary, in order that research could be directed to their solution. Work in this field was co-ordinated by the Nuclear Weapons Lethality Committee. This was an inter-departmental committee which was the link between the specialists working at A.W.R.E. and those in other Government departments. The staff of D.A.W.D., Ministry of Aviation, acted as executive to the committee.

2. Mr. Garrard said that information on EM flash had lagged behind that on other effects since instrumentation at earlier trials was specifically aimed at weapon design measurements. Much of the data had been accumulated incidentally in making other measurements, and was in consequence less complete than was desirable. However, a few trials had been instrumented to obtain the required parameters, and a sufficiently consistent reservoir of knowledge now existed for the formulation of a theoretical model adequate for engineering purposes.

3. Mr. Garrard showed comparative curves for damage radii for the main effects, and pointed out that only at low yields (of a few kilotons) did the radius for permanent nuclear radiation damage exceed those for blast and thermal damage. He then demonstrated the rate of emission, with a

time history beginning at 10 nano-seconds. Actually, 5% of the gamma radiation was emitted in the first microsecond, and 20% by the end of one second. To this must be added the neutron emission, which reinforced the gamma pulse by interaction with air and ground elements.

4. Typical curves for the pulse from a megaton and a nominal weapon were shown, giving time history at 1 mile and 2,000 ft. range (from burst) respectively. He pointed out that the EM flash hazard, deriving from the ionising nature of the gamma pulse, was a transient response causing misfiring, or loss of reference in memory circuits. Neutrons, on the other hand, caused permanent damage, changing the electrical characteristics of semi-conductor components. A normal criterion for damage to transistors would be 50% loss in current gain, but sensitivity could be much greater if adjustment were critical. Neutron damage was unlikely to be significant beyond the range for severe blast damage.

5. Mr. Popham gave a brief account of the mechanism by which the ionised sphere, and hence the electromagnetic pulse, is formed. Electrons are stripped from atoms in the vicinity of the burst by the high energy neutrons and gamma radiations. The consequent Compton electrons flow outward radially, until eventually slowed down and absorbed, and a large sphere of ionised matter results. Oscillations of this sphere produce the electric field observed at a distance. The size of the sphere only varies slightly with weapon yield. About 4,000 volts/metre is the order of magnitude of the electric field expected at its surface. Time history of the EM pulse shows a rapid rise time, in 10^{-8} seconds, a duration of about 10 to 30 microseconds, with frequencies about 10^4 cycles/second. Peak field strength increases with yield, scaling as $W^{1/3}$. Both the electric field and the corresponding magnetic field have been determined for ranges outside the ionised sphere but conditions within the sphere are not known with any accuracy. Extrapolation from observed values outside is not possible, since the highly conducting nature of the sphere distorts all the parameters.

6. Calculation of the induced currents from the field strength and dimensions of the conductor was not difficult. With a simple probe this became the product of field strength and probe length, and diminishes directly with distance from burst. Obviously with more complicated circuitry, comprising loops and sections differently aligned to the field, current strength could not be so easily assessed, and the simple calculation was not valid if the conductor approached the wave length of the pulse. However, it was apparent that large local voltages could build up, with results depending upon resistance or insulation in the circuit. Energies were comparable with those of normal radar, at distances of about 1,000 metres from the ionised sphere.

7. Mr. Miles asked if the ionised sphere could be regarded as a dipole, and Mr. Popham agreed that this rationalisation was used in calculating effects, assuming a vertical axis, which appeared to be justified. In reply to Mr. Law, Mr. Garrard indicated the variation of field strengths with distance as shown by curves for electric and magnetic fields. The relation

$E = \frac{10^7}{R}$ (E in volts/metre, R in metres) was true outside the ionised sphere, but within it fields tended to be constant as a result of the high conductivity.

8. Mr. Garrard quoted some results from an actual trial with a low kiloton weapon at ground level. Peak currents in long radial wires were about 3,000 amps at 1,000 ft., and 1,000 amps at 2,000 ft. Some asymmetry was demonstrated by currents of 1,000 amps induced in transverse sections of loops. These results showed the expected order of magnitude, but that prediction at any given site would in this case have proved unreliable. Pick-up loops inside screened containers had recorded small currents out to 4,000 ft. from ground zero. Core to sheath voltages of the order of

200 to 400 volts were observed at half a mile in insulated multi-core cables, compared with a few tens of volts in the case of bare metal sheath cables. Sheath to earth polarities reached a few kilovolts in the case of the insulated cables. Fuller details of these observations could be made available.

9. Mr. Ford said that the G.P.O. must be interested in EM flash effects on their communications equipments, and had in fact instigated an assessment of the threat to one installation by A.W.R.E. at the instance of M.O.D. Obviously all installations should be considered, but he thought that the reliability of the data, as evidenced by the shot described by Mr. Garrard did not justify the work required. He thought some further confirmation desirable before undertaking comprehensive calculations of the threat. Mr. Popham said that the main features of the electric and magnetic wave forms were consistent and not based on one shot only. Mr. Garrard said that this shot had been specifically instrumented for EM flash phenomena. It did answer some questions but raised others, particularly regarding the technique of measurement. Group Captain Chettle said that there was agreement on the most important features, i.e. the phenomena outside the ionised sphere and the nuclear radiation pulse. Effects on actual equipment must be assessed by, or for, the user, since the circuitry exposed was known only to him. Mr. Kilvington said he thought that, with a fundamental frequency near 10^4 cycles per second as quoted, damage to microwave radio relays was more likely to occur from induced currents. Mr. Garrard agreed, and said that the mixer and aerial connecting cable were likely to be vulnerable. Mr. Popham quoted an actual experiment in Australia, in which a microwave radar transmitter had been aligned toward a kiloton range burst while in operation at a range of about 10 miles. It had recovered after missing one or two pulses. Mr. Franklin asked what hazard was likely with coaxial cables used in Transatlantic lines, and Mr. Garrard said that limits could be calculated, though differing types of sheathing would introduce variable factors.

10. Mr. Morley said that Home Office VHF and UHF communications installations were hardened to a 5 p.s.i. level in respect of blast, and asked how significant the corresponding frequency components of the EM flash would be at such a range. Mr. Garrard said that 5 p.s.i. corresponded roughly with 10 KV/metre and as even 1 kilovolt/metre appeared to be at about 10 times the "C" damage radius there was obviously a hazard. It should be noted that the pulse, though generally similar to a lightning flash in effect, could not be discounted in the same way as an unlikely contingency. Given a nuclear burst, an EM flash was a certain consequence, its results only being uncertain. It was faster than a lightning flash, having a steeper rise to peak value and this might make certain types of protector ineffective. Mr. Popham said that A.W.R.E. had produced an analysis of the spectrum, giving the power within frequency bands. Mr. Sargeaunt said it was apparent that calculations must be done, and suggested that Home Office Communications might be the subject of a similar investigation by A.W.R.E. to that undertaken for the G.P.O.

11. Mr. Whitcher said that power installations were likely to be less sensitive than communications. If the EM pulse were regarded as severe lightning with 100% certainty, then he thought minor damage only need be anticipated. Lightning was a hazard with which they had learnt to cope. On the other hand, they were very significant users of communications, and they must take very serious note of the points made in this field. Mr. Mott said that there was an obvious threat to computerised control systems which were currently being developed. Overhead transmission lines might also be at risk, but obviously heavy equipment would be less vulnerable than transistorised circuits. He proposed to submit figures to the Automatic Control Committee (C.E.G.B.) and would consult the Ministry of Aviation on this. Mr. Garrard offered to co-operate in evaluating the systems and equipments in question. Mr. Popham said an environmental specification was required, to which equipment should be designed.

12. Mr. Firth asked how vulnerable were crystals, as used in UHF and VHF transmission, to this hazard. Mr. Garrard said that nuclear radiation represented the threat here and that although the crystals used for carrier frequency control single channel voice communications should not be seriously affected, as little as one roentgen could do permanent damage to very high precision crystals, e.g. of one in 10^{10} accuracy. Mr. Franklin said that crystals of this order of accuracy were used in the G.P.O., so that some consideration of effects on the systems concerned was merited.

13. Group Captain Chettle said that the pattern of investigation required could only be supplied by co-operation between 3 sorts of people:

1. Theoreticians and field experiments - What the bomb does?
2. Users - What is the threat?
3. Designers - What will equipment stand?

Co-ordination of the work under these headings was obviously necessary before calculations could be made. The approach by G.P.O./M.O.D. to A.W.R.E. should be fruitful, but was not necessarily open to all users. A.W.R.E. could supply, within limitations of available staff, data on the variations in time and space of the important physical parameters after the explosion of a given bomb in a given time and place. The operating authority must specify the threat. A.W.R.E. would rarely be able to assess the vulnerability of specific equipments to the effects they calculated; this should normally be a task for the equipment designer. Ministry of Aviation (A.W.D.2 (Effects)) had information and experience in this field and would be pleased to give advice where possible. The N.W.L.C., as the appropriate interdepartmental committee were concerned to see that interdepartmental co-operation on this kind of investigation was both possible and successful. Mr. Sargeaunt said that the meeting had been very illuminating, since the nature of the hazard had been imperfectly appreciated. The lines on which work must proceed were indicated, and the users must now make an appraisal on installations for which they were responsible, to determine where screening or modification was required.

Distribution:

Those present
Mr. L.T.D. Williams, D.G.A.W.
Mr. S.A. Hunwicks, D.A.W.D.

Meeting in Room 208, at 10·30, Tuesday Oct. 20th 1964.

List of those expected:-

NAME	DEPARTMENT	REMARKS
Group Captain Chettle Mr Garrard Mrs Wilkie	Ministry of Aviation A.W.D.	 Lecturer Secretary, N.W.L.C.
Mr Popham (Tel. Western 7266/3061)	Ordnance Board	Lecturer
Mr Sargeaunt " Leader Williams " Stanbury " Pavry " Miles.	Home Office, S.A.B.	
Sir Walter Merton Mr Firth ~~Mr~~ Collyer Mr Gelly " Potter " Law.	Home Office	
Mr Morley " Brooker " Watson " Glaysher	Home Office Communications Branch.	
Mr Ford " Kilvington " Franklin	G.P.O.	
Mr Mott " Witcher	Electricity Industry	Nominated by Min. of Power.
Mr Hurst	Ministry of P. Bldgs & Wks.	
Col. W.T. Armour	Ministry of Defence	Nominated by A.W.D.

XY/306/01

Effects of Electro-magnetic Pulse from a Nuclear Weapon on Civil Defence Interests

The meeting will be held in Room 208,
Horseferry House, Dean Ryle Street, S.W.1.
at 10.30 a.m. on Tuesday, 20th October, 1964.

AGENDA

1. Introduction. Mr. Sargeaunt and Gp.Capt. Chettle.

2. Effects

   (a) Nuclear Radiation at Early Times — Mr. D.J. Garrard.

   (b) (i) Electro-magnetic Pulse — Mr. E.D. Dracott.
   (ii) Induced Currents and voltages — Mr. T.S. Popham.

3. General Discussion.

Revised Draft Agenda

Proposed Symposium on Nuclear Weapon Effects, with particular reference to the effects of Electro-magnetic Pulse on Civil Defence interests, including Communications and Power

(To be sponsored by Ministry of Aviation, and held at the Home Office.)

	Estimate of Time
1. **Introduction**	
Mr. Sargeaunt and Group Captain Chettle	10 minutes
2. **Effects**	
(a) Nuclear Radiation	50 minutes
(b) (i) E.M. Pulse	
(ii) Induced currents and voltages	
3. **General Discussion**	1½ hours
	2 hrs. 30 mins.

NWLC/M(64)1 XY/337/02

MINISTRY OF AVIATION

NUCLEAR WEAPONS LETHALITY COMMITTEE

Minutes of the Seventeenth Meeting held on Tuesday, 30th June, 1964 in Room 458, St. Giles Court, W.C.2.

Present	Branch or Post	Representing
Mr. L. T. D. Williams	D.G.A.W.	In the Chair
Mr. J. K. L. Thompson	D.Sc.3 for Mr. Fakley	M.O.D.
Cdr. P. B. Grotrian	D.G.W./N.	D.C.N.S.
Mr. J. H. Williams	D.N.P.R.	M.O.D.(N)
Col. R. Bellingham Smith	M.G.O. Nuclear	M.G.O. & D.C.G.S.
Mr. J. W. Gibson	"S" Divn./O.B.	Ordnance Board
Gp. Capt. A. J. Peart	D.D.O.R.10 (R.A.F.)	D.O.R.3 (R.A.F.)
Col. T. W. Armour	G.W.(P. & W.) for Dr.Errington	C.G.W.L.
Mr. R. D. Starkey	A.D./A.D.R.	C.A.
Miss V. A. Davies	M.E./R.A.E. for Mr. Bisby	D./R.A.E.
Mr. F. E. J. Girling	R.R.E.	D./R.R.E.
Mr. E. R. Drake Seager	S.F.P./A.W.R.E.	D./A.W.R.E.
Mr. S. D. Abercrombie	S.P.A.2/A.W.R.E.	D.A.W.R.E.
Col. H. W. Whitcher	D.G./A.M.S.	Panel N1 Sub.Cp. N.
Mr. S. A. Hunwicks	D.A.W.D.	M.O.A.
Gp. Capt. P. F. Chettle	A.D./A.W.D.2	M.O.A.
Mrs. M. E. Wilkie	A.W. Plans	Secretary

The following also attended

Mr. P. J. Atkins	S.F.P./A.W.R.E.	D./A.W.R.E.
Mr. J. C. Litton	"S" Divn./O.B.	Ordnance Board
Mr. F. H. Pavry	S.A.B./H.O.	Home Office
Mr. D. J. Garrard	A.W. Plans	M.O.A.

Apologies for absence were received from .

Mr. D. C. Fakley	M.O.D.
Mr. D. H. Chaddock	D. of A. (R. & D.)
Mr. G. J. Laing	D. of A. (R. & D.)
Mr. G. R. Stanbury	Home Office
Mr. J. D. Davies	A.W.R.E.

Item 1. Minutes of the last meeting

1. The minutes of the last meeting were accepted without amendment.

Item 2. Matters arising

2. Actions 16-1 and 16-2. Consideration of these actions was deferred to Items 4(b) and 3(c) on the Agenda, respectively.

3. Action 16-3. Mr. Gibson said that the Committee's directive had been noted. This must, of necessity, be a continuing action. Draft minutes of the last Sub-Group N meeting had been prepared and were now under consideration by the U.S. and Canadian members before final publication. He said that the question of these minutes being made available to the A. B. C. A. Standardization Group had not yet arisen, but agreed that it was unlikely that such a request could be granted.

4. Actions 16-4 and 16-6 were noted as having been completed.

5. Action 16-5. Mr. Garrard said that the original directive had been complied with, and that a contract had now been made through R.A.E./Weapons Dept. with Standard Telecommunication Laboratories, who were now engaged in drawing up a programme of work. A meeting with interested parties had been held to pass on information from the recent JOWOG-6 visit to U.S.

Item 3. Tripartite Technical Co-operation Programme. Sub-Group N. activity

6. Mr. Gibson said that the last Sub-Group meeting in October 1963 had already been discussed by the Committee. The next meeting was proposed for October 14th-15th, preceded by a Panel N1 meeting in September, both taking place in Canada. Panel N2, most of whose personnel were in Suffield for the current trial, planned to have a meeting there following the 500-ton explosion. Panel N3 had held its first meeting in U.S. in April, and details of this and future meetings would be given by Mr. Drake Seager. It was planned to review reports from the Panel Leaders in September, as a preparatory briefing for the October meeting, and, among other subjects, the U.K. views on the future use of the Suffield site should be defined by this time.

Item 3(a). Report from Panel N1

7. Col. Whitcher referred to the last Panel N1 meeting in October 1963 and said that difficulties in implementing actions arose from the delay in issuing minutes, since these were in effect the authority required for any action. In this case the U.S. were responsible for the issue of minutes. The Panel noted and decided to support the U.K. work on biological effects of nuclear radiation. This included neutron effects on large animals, which was proceeding, but for which firm results were awaited before publication, and the effects of low gamma dose rates upon rats. Here, using food consumption as indicator of the effect, a definite response at 2.7 r./hr had been established, with uncertain results as yet at lower dose rates. The current Services trials of the U.K. chemical protective garment were noted, and it would be compared with the efficacy of the Canadian Nimbus cloth, when the final report on the latter was received. The need for radiac instrumentation in the field had been queried by the Panel, but the logical step of representing this view at the next Quadripartite Standardization Group meeting could not be taken in the absence of the minutes. The Quadripartite Group had already fixed the standards for water potability so that there was no need for the Panel to consider this question further. In conclusion, Col. Whitcher referred to the Suffield trial and said it was hoped that this would produce more information on blast effects on large animals.

8. Mr. Gibson said that the T.T.C.P. procedure was for meetings to be held in rotation in the three participating countries with the host country providing the Secretary. In the case of the Sub-Group meetings, issue of the formal minutes is the responsibility of the Executive member. For panel meetings it had been proposed that the host country should provide the Chairman as well as the Secretary, and, if this was agreed, it seemed reasonable that the host country should also issue the minutes. Col. Whitcher agreed with this, and said that the Panel N1 draft minutes in this case had been prepared by the U.K., but left for the U.S. to issue, as this was considered a function of the permanent administration between meetings. Mr. Gibson said that the degree of authority, apart from co-ordination, of the Sub-Group with reference to its Panels was not clear to him. He proposed to follow the procedure adopted by other Sub-Groups, of collecting reports from the Panels and drawing up an agenda for the full Sub-Group meeting from their recommendations. The Chairman said that this pattern seemed sensible. Col. Whitcher said that the work of Panel N1 was further hampered by the lack of any clear authority to support its work, which by reason of its diversity required the co-operation of different establishments, including the M.R.C., Aldermaston and hospitals. He did not propose increasing the formal membership of the Panel, since

14. Mr. Abercrombie gave an account of the Symposium on E.M.P. effects at Bedford, Massachusetts. This was held 22nd-26th May, and was therefore concurrent with some of the other visits arranged through JOWOG-6. Discussions covered the further analysis of the "Small Boy" results, and Mr. Abercrombie noted that this had resulted in closer agreement between U.S. and U.K. on their interpretation. A summary of the U.K. work on the "close-in" field was given. The effects of the nuclear radiations, in particular of the secondary gamma derived from the neutron pulse, on the form of the electromagnetic pulse was examined. There was a session on shielding devices, including protection of cables, and an account of simulation work at A.F.W.L. Devices used for this include an elaborate tapered structure, 30 feet in width, which produces a travelling wave, and a trailer which carries a Marx generator, consisting of 5 units each producing 2 megavolts, which can be used in various combinations. The problems of missiles in flight were examined, but U.K. members were excluded from discussions of missile systems for reasons of security.

15. Mr. Abercrombie also reported on the JOWOG-24 meeting in the U.K. from 23rd-25th June, 1964, which also dealt with the E.M.P. field. There was an exchange of data, and both U.S. and U.K. are preparing summaries of the information so far established. The interpretation of the "Small Boy" results is continuing, but is hampered at A.W.R.E. by lack of staff. The main effort is being concentrated on the formulation of a satisfactory "close-in" theory, since phenomena within the ionised sphere are imperfectly understood. There are A.W.R.E. experiments at Suffield to record the E.M. effects, at 30 feet above and below ground, the fireball expansion and the distortion of the earth's field. There is current U.S. work on underground shots in Nevada. A technique for containing the burst had been satisfactorily developed, but electro-magnetic effects were distorted by the conditions.

16. The Chairman asked if electro-magnetic effects were regarded as a real hazard under operational conditions, and Mr. Garrard said that this was the U.S. opinion. It was apparent that the problem depended upon the design of the particular equipment and with the U.S. reticence on missile systems the information available was incomplete.

17. Item 4(b). E.M. Flash Hazard to Equipments

Gp. Capt. Chettle referred to Action 16-1, requiring the formation of a small panel to co-ordinate knowledge of this hazard. He found that, in effect, this already existed in the E.M. Flash Panel of the Committee, which had itself been unable to proceed to the production of a guide for designers and producers. He had found considerable ignorance of the problem among users, who were not convinced of its importance. Designers had noted the effect, but believed other hazards to be of greater importance. He proposed to arrange discussions between those responsible for operational requirements in specific fields and a small team of experts, effectively the E.M. Flash Panel. He hoped in this way to identify specific problems, in each field in which they existed. He had already started action to bring about the first of these short seminars which, for convenience would be with M.O.D. (Air) operational requirements and signals staffs. If this was successful the discussions would be repeated with other bodies. Mr. Pavry said that he would like to be kept informed so that the Civil Departments could take advantage of these arrangements.

18. Mr. Thompson said that the Ministry of Defence had received a request from Bomber Command, to assess the danger to communications arising from E.M. flash. This problem had been referred to A.W.R.E. Mr. Pavry said that the G.P.O. were involved in this, and there were also Civil Defence and telecommunications aspects. He had been informed by the G.P.O. that M.O.D. authority was needed for action. It seemed that this had now been obtained. Mr. Abercrombie said induced currents in underground cables and land-lines must be considered, along with the power supply and telecommunications involved. There had been a meeting at Aldermaston with the Bell Telephone Co. to correlate effects with results from Small Boy. They would supply an answer related to the estimated field strength. The Chairman said that he was glad to note that there was now a specific problem on the way to solution. He asked Gp.Capt. Chettle to keep in touch with this work. Mr. Girling said that the diverse factors

contributing to this problem showed the difficulty for those concerned with weapons systems. Operational requirements could only refer in vague terms to the hazard, and Gp. Capt. Peart agreed that this was what had happened at the Air Ministry.

Item 4(c). E.M.I. Report of Fuze Experiments at D.O.R.F.

19. Gp. Capt. Chettle said that a meeting chaired by D.S.R.(L) had considered this report, and agreed that the results should have a wider distribution than that made so far. R.R.E. had agreed to prepare an abstract to summarise the knowledge gained at these tests. Mr. Girling said that the establishment of mistriggering and permanent damage levels with respect to the reactor pulse did not necessarily establish where these levels cam in a bomb environment. He recognised two sources of error in attempting translation of results in terms of a reactor environment to those of a bomb environment. It would be possible either to proceed beyond the limits justified by the data, or by keeping within the established limits, to produce an interpretation too vague to be of use. The mistriggering mechanism, different for each fuze, also appeared to differ for the two types of environment. He was at present unsure of the value of the paper that could be extracted from these results. Mr. Garrard welcomed this analysis and agreed to discuss the results further with Mr. Girling.

Item 5. N.A.T.O. Symposium on Effects of Nuclear Weapons on Underground Structures

20. The Chairman said that he must omit this item from the Agenda in view of the time taken over the foregoing discussions, and apologized to those interested.

Item 6. Any other business

Item 6(a) Paper NWLC/P(64)4

21. The Secretary announced the distribution of Paper NWLC/P(64)4 to U.S. and Canadian recipients of A.W. Plans Note 45, which was the primary reason for its production, in response to their request at the last Sub-Group N meeting. It had also been made available to Committee members. Miss Davies asked why, if "DISCREET" material had been made available to Canada, as in this case, some reports in this category had been omitted. The Secretary replied that this had been agreed between the originator and T.I.L., who had prepared this bibliography. The Chairman said that it seemed to be a very good piece of work, and asked the Secretary to express the Committee's appreciation. ACTION Secretary

Item 6(b). Reports on "Buffalo" and "Antler" trials

22. Mr. Drake Seager said that he would like to have the Committee's opinion on the desirability of completing the publication of the reports from these trials. There were about 6 (of 40) outstanding, and these were unlikely to be printed unless the Committee asked for them, since Technical Services at A.W.R.E. regarded other work as more pressing. The Chairman said that he had previously observed with concern that A.W.R.E. apparently face difficulties in producing reports in times comparable with other Establishments and that delays of some years after the carrying out of the relevant experiments were not unknown. In the cases mentioned by Mr. Drake Seager, the experiments had been carried out more than six years previously. He thought it would be most unfortunate if Departments were to be deprived of even a part of the information derived from these trials, which had cost so much in money and effort to mount, and he said that the appropriate Division of A.W.R.E. should be asked to expedite the publication of these missing reports. ACTION MR. Hunwicks

Item 7. Date of next meeting

This was left open, to be notified at some future time.

Mr. R. Firth

Electromagnetic Effects of Nuclear Explosions

You sent me a minute on this subject on the 2nd November.

We had a meeting with Mr. Garrard of DGAW, Ministry of Aviation, about 9 months ago prior to his leaving for the U.S. to participate in the "Small Boy" trial in Nevada in the Summer. Mr. Garrard was in Washington again recently to attend a symposium on 13/14th November at which some of the results of the trial were discussed, and a brief note of this meeting is attached.

We have now had the opportunity of meeting Mr. Garrard again together with representatives of Communications Branch and the GPO and hearing some account of this work. While very interesting scientifically it is obvious that at the present time there are so many unexplained anomalies that it would be quite impossible to recommend any particular course of action until we have further information.

A representative of the Bell Telephone Company - one of the major contractors in the trial - will be in this country soon and we shall take the opportunity of talking to him. In the U.S. a large body of experts has been recruited to try and make some sense of the results, and I doubt very much whether we shall hear anything more before the Summer at the earliest. In the meantime Garrard will be working on his own results and will let us have a copy of his report as soon as it is ready.

My general feeling is that the normal precautions that are taken against lightning ~~both~~ in communication circuits ~~and in power lines~~ will be a partial safeguard for communication circuits and that more thought is required as to what should be done for power.

(SGD.) H. A. SARGEAUNT

Chief Scientific Adviser
4th January, 1963.

I hope after the "Bell" meeting that I shall not have to be so negative.

Basic-principles E.M.P. protection

1. Lightning Protection for all power cables; power supply as much as possible by a power station within the hardened facility
2. Put wires in boxed, grounded circuits
3. Use ground-screen over air-conditioning outlets. Ground all ducts
4. Ground rebar especially if tack-welded
5. Install largest available lightning arresters on power-system transformators
6. Install spark gaps on telephone lines
7. Ground cable outer-shields
8. Ensure that signal cable shields are well grounded at point of entry
9. Bury cable as deeply as economically feasible
10. Connect the water pipes and other metallic entries into the grounding system
11. Install lightning arresters on antennas and input leads which cannot be directly grounded
12. Educate personnel in protection practices
13. Adopt protection procedures to particular areas
14. Do not interrupt shielding provided by outer conductor when a lead is tied to coaxial cable
15. Ground all non-essential equipment
16. Because natural grounds are often unsatisfactory use massive counter poise at each site
17. Ensure that entire conduit system is well grounded
18. Avoid use nonconducting lubricants when assembling conduit pipes
19. Ensure that electrical contact exists between conduit and terminal box
20. Install grounding strap from terminal box to door at box
21. Specify EM-testing of the completed installation with appropriate simulation devices to ensure adequate protection
22. Use dry rather than oilfilled transformators
23. Provide surge protection for emergency power equipment

24. Use lightning protection on all above ground lines:

25. If power equipment supplies several sites, install lower value fuse at the equipment end

26. Use fuses rather than circuit breakers ← Garrards U.S. Manual – in which these principles appear – reverses this preference. F.I. 8/12/66.

27. Do not use slow-blow or delay fuses

28. Design fuses within safety margin

29. Provide automatic closing doors with recessed fits for shielded rooms

30. Use dehumidified storage for materials to be used in dehumidified areas

31. Locate poor electrical contact points between screened areas by applying voltages across the areas

32. Put single-phase protection on all three phase equipment

33. Ensure that the intrasystem wiring conforms to a "tree" or radial wiring scheme

Copies went to:- Brooker & G.P.O. (see doc. 65)
UKWMO
MPBW
M of Power
} see D.O. sheet CD 16171

XY/325/05
XY/306/04

NWLC/P(65)3

Effects of Nuclear Weapons

E.M.P. Workshop at Santa Barbara
21st-30th June, 1965

Mr. S.D. Abercrombie and Dr. E.D. Dracott of A.W.R.E. and Mr. D.J. Garrard of Ministry of Aviation were invited by D.A.S.A. to participate in this project. The idea was to get together those people directly concerned in the determination of the electromagnetic flash signal from nuclear explosions and in the evaluation of its interaction with systems, with a view to writing a comprehensive document as a basis for future design. It was felt that the present moment was opportune because the cessation of atmospheric testing has meant that little more information is to be expected in the foreseeable future, and because the large theoretical effort which has been put into this study is about to be diverted on to other problems.

A group of about 30 people therefore met at D.A.S.A. invitation at the D.A.S.A. Data Centre G.E. Tempo, Santa Barbara, California from the 19th to the 29th June, 1965. After a brief introductory talk the party divided into four sections each charged with writing one chapter of the proposed manual. These dealt with:

1. Basic phenomena.
2. Electro-dynamics - Close-in EM field calculations.
3. EMP induction into systems.
4. Experimental techniques.

Details of these chapters and of some of the authors responsible are given in Appendix A.

The tentative schedule for completion of the EMP summary document is at Appendix B, from which it can be seen that copies are due to be in the hands of users (in U.S.A.) during October of this year. It is not intended that the draft be submitted to U.K. participants, as this would incur disproportionate effort in clearance and transmittal and would be impracticable in the time scale. What is more important is that we should press, and press hard, for copies of the final document to be released to us as soon as possible. It is realised that copies released to U.K. will be incomplete, if only in that the sections dealing with plans for future field trials, as well as of references to specific U.S. systems will have to be eliminated in accordance with current U.S. security procedures.

Mention was made of following up this document with a proper EMP handbook, but periods of a year or more hence were being contemplated in this connection and it would be most undesirable to have to await publication of such a document. It is stressed that we shall not get either document unless we ask for it, as shown by the fact that U.K. participants in last year's EMP conference at Boston have not been sent copies of the proceedings at the same time as U.S. participants.

It is intended that technical papers dealing with individual items arising from my visits to various Laboratories under the aegis of JOWOG-6, and from my attendance at the I.E.E.E. symposium at the University of michigan on Nuclear Radiation effects on Electronic components be written shortly.

D J Garrard

A.W.D.2 (Effects),
15th September, 1965.

D.J. GARRARD.

PROPOSED OUTLINE AND RESPONSIBLE AUTHORS

ELECTROMAGNETIC PULSE SUMMARY

Chapter 1. Basic Phenomena - Current and Conductivity (Malik)

I. Source Description (Malik)
   1. Prompt Gammas
   2. Air/Ground
   3. Fission Products

II. Gamma Ray Transport (Schaefer)
   1. Scattering
   2. Source Geometry
      a. Isotropic
      b. Point
      c. Shell

III. Air Chemistry (Darrah)
   1. Conductivity
      a. Tensor
      b. Scalar
   2. Charged Particle Density
      a. Lumped parameter
      b. Individual reaction
   3. Mobility
      a. Field dep.
      b. Water dep.

IV. Recommendations for Future Work (Group)
   1. Underground
      a. Source strength
      b. Time history
      c. 14 Mev neutrons
   2. Interpretation of Monte Carlo
   3. Air chemistry

V. References

Chapter 2. Electrodynamics - Close-in EM Field Calculations (Longmire)

I. Introduction (Longmire)

II. The Spherical Symmetric Case (Longmire)
   1. Radial E. Field
   2. Time, altitude, yield

III. Asymmetric

1. Near surface (Longmire)
    a. Close-in fields (Longmire)
    b. Not close-in (Dinger)
    c. Grounds (Dinger)

IV. Free-air Burst Bomb and Air Asymmetry (Suydam)

V. Free-air Burst, Geomagnetic Effect (Karzas)

VI. X-Ray Effects (Karzas)

VII. M H D Effects (Reinheimer, Dracott, Whitaker and Dyle)

VIII. References

Chapter 3. EMP Induction into Systems (Graham)

I. Fields in Ground (Dinger)

II. Electrical Properties of the Ground (Scott, et al.)

III. Cables: Types, Characteristics, Terminations (All)

IV. Methods of Calculating Induced Cable Current

1. Longmire (Haas)
2. SRI (Whitson, Vance)
3. AFWL (Graham, Marston)

V. Missile and R/V Coupling (Merewether)

VI. Computer System Coupling (Graham)

VII. Direct Gamma and X-Ray Effects (Longmire)

VIII. Recommendations for System Design (All)

IX. Recommendations for Future Work (All)

X. References

Chapter 4. Experimental Techniques (Wouters)

I. Non Nuclear Simulation

1. Phenomenologic Application
    a. Nuclear radiation, facilities and exposure (Baum)
    b. EM field experimental schemes, modeling (Bostak, Abercrombie)
2. Environmental Simulators (Garrard, Abercrombie, Bostak)
    a. System exposure requirements
    b. Energy sources
    c. Free field sources

II. Nuclear Simulation (Wouters)

1. Introduction, Unique Features, Atomic Bursts, Confinement and consequences, Implication of Bomb Simulation

(Reference Sensors)

77

Ministry of Aviation Memorandum

FROM : (Branch and Address) AWD 2 Effects

Telephone No. Extn. 2092

Our ref.: XY/306/04.

TO: F. V. Pavry Esq
Scientific Advisers Branch
Home Office, Horseferry House

8. 6. 1966

Your ref.:

Dear Frank

E. M. P.

M125/DASA/1

CD16249

Very many thanks for the sight of the attached note by Don Smith of Dasa. I have taken numerous copies, (of which 1 is here attached) as it is explicitly declassified, - the first time the magnetic field has been stated below Secret Atomic. I am discussing this with AWRE. I suspect that

L.H.IR

Use the reverse for continuation or reply as necessary.

pto.

he may have got away with it by omitting time statements.

Do you think I ought to arrange to join this working party? I'm not clear on its terms of reference.

Y'

Derrick

See Garrard's note on classification. He is obviously interested that this has been officially down-graded by DASA. This report - "Effects of the Electromagnetic Pulse" - was obtained by Mr. Stanbury at the May 1966 meeting of the NATO Scientific Working Party)

F. H. Pavry

17th June, 1966

SECRET

80

MINISTRY OF POWER
Thames House South, Millbank, LONDON S.W.1
Telephone: Abbey 7000 / 1007

Our reference: 15/9/01 Pt.2

22nd July, 1966.

Your reference:

Dear Pavry,

E.M.P. EFFECTS

On 15th June you sent us on loan Copy No. 240 of a document NATO SECRET SA-6-2-04(SUS)1 - Seminar on The Effects of Nuclear Weapons on Underground Structures - to see pages 21-38 which relate to E.M.P. Effects.

Is there any objection to Messrs. Mott and Whitcher of the Electricity Supply Industry having sight of this document before we return it to you? Both have been brought in on this subject and, as you know, have received papers from you. Both have responsibilities for defence planning arrangements in their industry and are security cleared to see documents up to and including SECRET classification.

Yours sincerely,

H L Spencer

(H. L. Spencer)

F. H. Pavry, Esq.,
Scientific Adviser's Branch,
Home Office,
Horseferry House,
Dean Ryle Street,
S.W.1.

SECRET

VT

With Compliments

of Mr.Gelly

Warning and Monitoring Branch
Home Office
Horseferry House
Dean Ryle Street
S. W. 1

Tel: VIC 6655 Extn. 680

83.

COPY

CDA/59 36/18/2

Mr. R. H. F. Firth
Communications Branch

Electro-Magnetic Pulse

I am trying to establish the present position on this subject and have written to the Chief Scientific Adviser asking him to let me know what progress, if any, has been made on the scientific side since he circulated his note of 28th January 1966 (ref.SAG/62 10/156/2).

2. Would you, therefore, be good enough to bring me up to date on the position so far as Communications Branch is concerned and, in particular, advise me on the following points:-

(i) Was Elgood able to raise the question of progress in the EMP field with the Chairman of the Electronic Warfare Sub-Committee, as indicated in Ford's letter of 6th September 1965 to Brooker (ref.COM/64/71/4/1), and if so with what result?

(ii) Has Brooker heard anything further from Ford about the latter's letter of 12th May 1966 to Chew of the Ministry of Defence (Air)?

(iii) What has happened to the suggestion first made by Ford in his letter of 6th September 1965 to Brooker and later repeated to Brooker in his letter dated 22nd March 1966, about studying the effects of EMP on the warning and monitoring network?

3. Some three years have passed since Warning and Monitoring first raised the problem of EMP; I am sure you will agree that it is time we took stock and decided what, if anything, can be done to produce some results.

(Signed) J. Gelly

29th September 1966.

Warning and Monitoring Branch

From: Air Commodore J.H. Greswell, CBE, DSO, DFC.

HEADQUARTERS
ROYAL OBSERVER CORPS
Bentley Priory, Stanmore, Middlesex
Telephone: Bushey Heath 4000, ext. 206

Please address any reply to
THE COMMANDANT
and quote: ROC/JHG
Your reference:

20th December 1966

Refers to EMP Working Group's report, "Electromagnetic Pulse Phenomenology and Effects (U)"; DASIAC Special Report 41 (DASA 1731), April 1966, classified: "Secret Restricted Data".

(DASA 1731 = AD372860L.)

Mr. J.P. Gelly
Warning & Monitoring Branch
Home Office
Horseferry House
Dean Ryle Street
London S.W.1

Dear John,

I recently attended a talk by Mr. Abercrombie of A.W.R.E. on the effects of E.M.P. etc generated by a nuclear explosion, on communications and on electrical and electronic equipment and cables. He said that much research on this had been done by the Americans and that the basic technical data is contained in an unclassified report issued by them reference DASA 731 entitled "Electro-Magnetic Pulse Phenomenology"

I understood that this report contains a very great deal of technical information, graphs, tables etc, from which it is possible for users to interpret the possible effects of E.M.P. on their equipment and communications.

Mr. Abercrombie's lecture dealt only with the principles of the E.M.P. phenomena as contained in the American reports and he emphasised that, because the physical layout and conditions of the communications and equipment of each user varied so widely, it would be inappropriate for him or A.W.R.E. to undertake studies of effects on behalf of users. He quoted the case of a RAF Command to whom he had given his lecture, later sending him a long list of questions, all of which could have been answered by the Command's technical staff by reference to the data contained in the American report. I gather that this apparant lack of co-operation has led to certain ill feeling and has wrongly been interpreted that only scant information exists about E.M.P. The fact is that only limited work has been done on applying the known data to communications networks. In my opinion this work is not properly the task of A.W.R.E. but should be undertaken by local technical staffs, based upon data provided by organisations such as A.W.R.E.

I know you are concerned about the effects of E.M.P. on our communications, and I thought the above might be helpful. It seems to me that, if S.A.B. could get hold of a copy of DASA 731, much work could be done in this respect. I am told that only a few copies of the report exist in this country but no doubt Home Office could get more from America. I have tracked down one copy with AWD2 in the Ministry of Aviation.

Yours sincerely,

J.H. Greswell

Mr Gelly showed me this letter on Dec. 22nd. I explained that there has been some misunderstanding. DASA 1731 (not 731) is the U.S.

HOME OFFICE

SCIENTIFIC ADVISER'S BRANCH

Notes of a meeting held on 10th January, 1967, in room 542, Horseferry House to discuss:-

Electro-magnetic Pulse

Present:-	Mr. Stanbury	Scientific Adviser's Branch, H.O. (Chairman)
	Col. Barnes	Cabinet Office
	Mr. Garrard	A.W.D.2., Ministry of Aviation
	Mr. Wright)	G.P.O.
	Mr. Rogers)	
	Mr. Gelly)	Warning and Monitoring Organisation, H.O.
	Mr. Potter)	
	Mr. Lane)	
	Mr. Morley)	Communications Branch, H.O.
	Mr. Brooker)	
	Mr. Pavry	Scientific Adviser's Branch, H.O.

Mr. Stanbury said he had called the meeting to bring all concerned up-to-date on E.M.P. He had been prompted to do this because of two communications from Mr. Gelly:-

(1) a minute dated 29th September 1966, in which he said he was trying to establish the present position, following a minute from the Chief Scientific Adviser in January 1966. (In that minute C.S.A. had reported the conclusion of the Nuclear Weapons Lethality Committee that the research effort on E.M.P. was inadequate.)

(2) a letter dated 26th December 1966 from the Commandant of the R.O.C. to Mr. Gelly, about a lecture given by Mr. Abercrombie at Fighter Command. The Commandant reported that Mr. Abercrombie had said that basic technical data were freely available in an unclassified American report, and that local technical staffs could, with the help of that report, solve their problems.

Mr. Stanbury dealt with this second item first, saying that there had, it seemed, been a misunderstanding at Mr. Abercrombie's lecture. The Scientific Adviser's Branch had been aware of the report in question for some time, since Mr. Garrard had kept them informed of his efforts to produce an edited version of low classification: but the report itself has all along been extremely highly classified. Mr. Abercrombie had been asked about his lecture, and denied that he had said the report was unclassified.

As regards a lowly-classified version of the American report, Mr. Garrard said he had completed his draft, and it is now with the American authorities, whose approval is necessary before it can be made available. He hoped that approval would be forthcoming, and that it might be possible to issue the report within a few months, but it depended on how quickly the U.S. authorities acted.

With regard to Mr. Gelly's first point, Mr. Garrard said that (following the comments of the N.W.L. Committee on the lack of adequate research) the Ministry of Defence Weapons Defence Committee had set up a Working Party to advise on how to solve the problem.

Col. Barnes said he was associated with a separate study of E.M.P. by the Ministry of Defence. A report was soon to be made available through the Cabinet Communications Electronics Space Committee, and Col. Barnes said he would try to make copies available to the Home Office.

SECRET

DISCREET

SECRET

SECRET

SECRET

MOD Form 45B

PRO

MINISTRY OF DEFENCE

18 Sept 00 (c)

Registered file number D/407/104/11/10

Date opened 17/8/70

1. ATTENTION IS DRAWN TO THE NOTES ON THE INSIDE FLAP
2. ENTER NOTES OF RELATED FILES ON PAGE 2 OF THIS JACKET

DIVISION

D. Sc. 6.

FOR REGISTRY USE ONLY

SUBJECT

NUCLEAR WEAPON EFFECTS — SYMPOSIUM — DECEMBER 1970.

Referred to	DATE	Referred to	DATE	Referred to	DATE	Referred to	DATE

DEFE 7/2401

CLOSED 10 - 3 - 76.

DISPOSAL or PA Action

See note on file flap

SR 1999

DOWNGRADING

(to be completed when the file goes out of current use)

(i) This file may be downgraded to:—

* CONFIDENTIAL
* RESTRICTED
* UNCLASSIFIED

on (Insert DATE)..........

OR

(ii) Return for Review

on (Insert DATE)..........

.... CERTIFYING OFFICER

.... APPOINTMENT AND BRANCH

.... DATE

SECRET

HPW 858861 33M 9/71

MOD Form 136

Minute Sheet No. 1 Reference 407/104/11/10.

Minutes and Brief Details of Enclosures	Clas.	Encl. No.
M.1.		
S.W.L.S. /550 - C.N° 2 of 3 d.d. 10/12/70. AWRE Programme of Work.	S	23.
M2.		
DEC. 1970. - Min. + E's (PHOTOS) from A.S.W.E. ref XRS 3/9.4/1920/70 - N.W.E. Symposium 11/12/70.	S	27
M3.		
19/4/71. L.M. from D.O.T.I. ref CS 68/506/A2.	S	31.
M4.		
2/70 Report - Collated Papers Presented at the N.W.E. Symposium held on 11/12/70. - C.N° 250 of 250 ref. 407/104/11/10. 128 Pages.	S	28/1
M5.		
17/11/71 Letter from RARDE ref FCR/872/011 cov. 'Speech notes' - NUC. HARD. SYMP. - Serial 6 (A1) ref S220/71 - C.N° 2 of 7	C/S S	44.
M6.		

SECRET

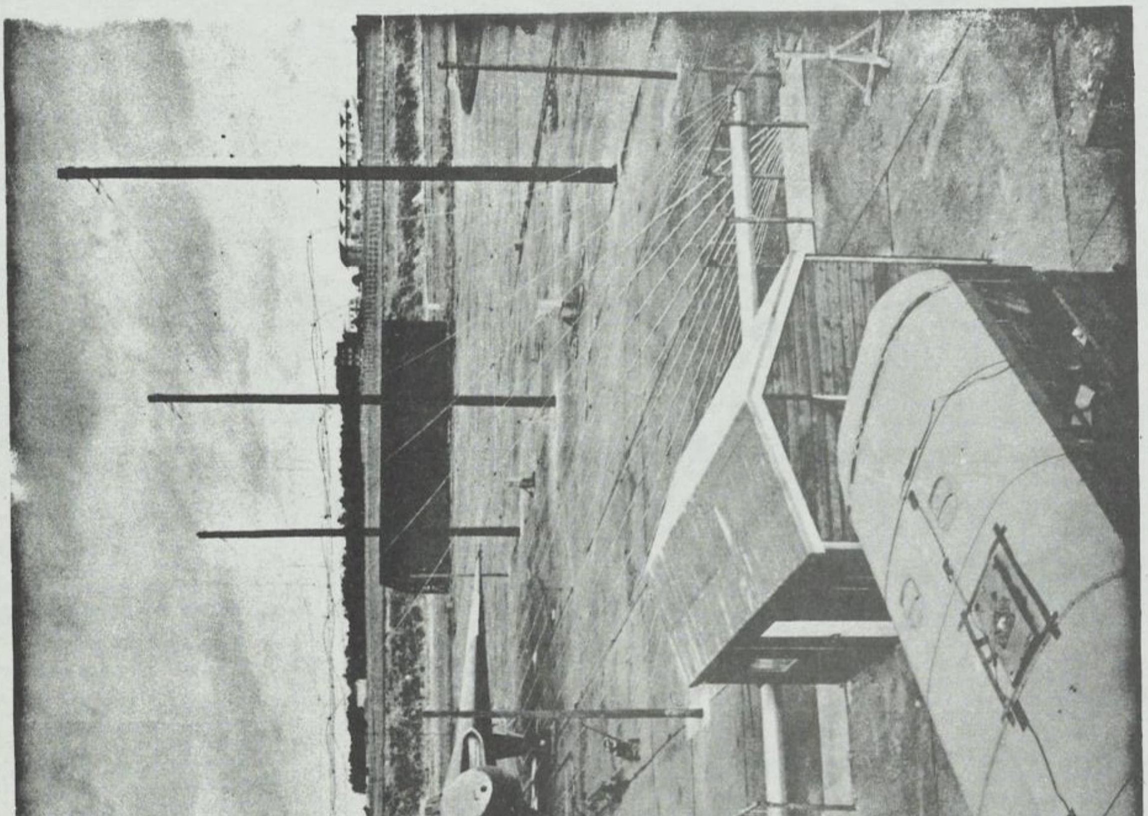


FIG. 1.

SECRET

4 Conclusion

In the two years since we first started work we have begun to understand some of the problems caused by EMP. A degree of confidence has been gained from this experience, but it is recognised that the greater part of the task lies in the future and there is still much work to be done.

EMP simulator test of tank, Nuclear Weapons Effects Symposium, 11 December 1970 (UK National Archives, DEFE 7/2401)

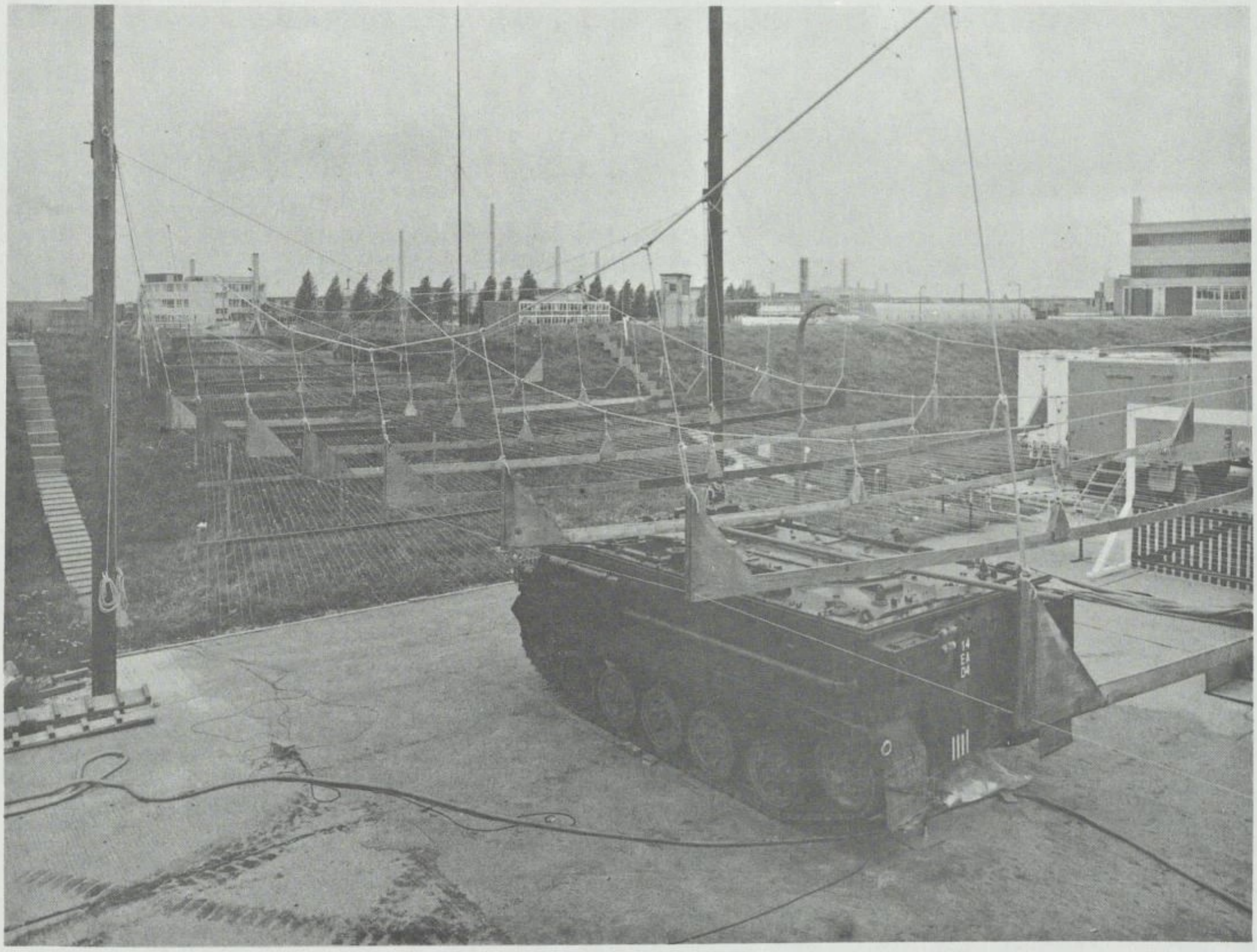


Figure 1

AWE: SDTN No 3/94

ATOMIC WEAPONS ESTABLISHMENT

DIRECTOR SAFETY AWE

SAFETY DIVISION TECHNICAL NOTE 3/94

A SUMMARY OF THE EFFECTS OF NUCLEAR WEAPONS

A C WOODVILLE

June 1994

AWE: SDTN No. 3/94

ATOMIC WEAPONS ESTABLISHMENT

DIRECTOR SAFETY AWE

SAFETY DIVISION TECHNICAL NOTE 3/94

A SUMMARY OF THE EFFECTS OF NUCLEAR WEAPONS

WITH REFERENCE TO THE UK ATMOSPHERIC NUCLEAR WEAPONS TEST PROGRAMMES 1952 - 1958

A C WOODVILLE

Section Leader ....
MHP/PDS (C&DE): T P Maish MSRP

Issue Authorised ....
MHP: G C R Sallit MSRP

Approved ....
D Safety: Dr G Ballard

Director Safety AWE
Aldermaston
Reading
Berkshire RG7 4PR

June 1994

34220004

TABLE 1

UK ATMOSPHERIC NUCLEAR WEAPONS TESTS IN AUSTRALIA

Operation and **Location**	**Date** and **Time** (GMT)	**Site**	**Emplacement**	**Altitude** (m)	Best Estimate of **Yield** (kt)
HURRICANE Monte Bello, WA	03 10 52 0000Z	Lagoon (12m deep)	Aboard HMS Plym	-3	25
TOTEM	14 10 53 2130Z	T1	Tower	31	10
Emu Field, SA	26 10 53 2130Z	T2	Tower	31	8
MOSAIC	16 05 56 0350Z	G1 Trimouille	Tower	31	15
Monte Bello, WA	19 06 56 0214Z	G2 Alpha	Tower	31	60

TABLE 1 Continued

Operation and **Location**	**Date** and **Time** (GMT)	**Site**	**Emplacement**	**Altitude** (m)	Best Estimate of **Yield** (kt)
BUFFALO	27 09 56 0730Z	One Tree	Tower	31	15
Maralinga, SA	04 10 56 0700Z	Marcoo	Ground Surface	0	1.5
	11 10 56 0557Z	Kite	Airburst	150	3
	21 10 56 1435Z	Breakaway	Tower	31	10
ANTLER	14 09 57 0505Z	Tadje	Tower	31	1
Maralinga, SA	25 09 57 0030Z	Biak	Tower	31	6
	09 10 57 0645Z	Taranaki	Balloon suspended	300	25

TABLE 2

UK ATMOSPHERIC NUCLEAR WEAPON TESTS IN THE SOUTH PACIFIC

Operation and Location	Date and Time (GMT)	Site	Emplacement	Altitude (m)	Best Estimate of Yield
GRAPPLE	15 05 57 1937Z	Off Malden Island	Airburst	2200	0.3 Mt
Christmas Island	31 05 57 1941Z	Off Malden Island	Airburst	2400	0.7 Mt
	19 06 57 1940Z	Off Malden Island	Airburst	2400	0.2 Mt
GRAPPLE X Christmas Island	08 11 57 1747Z	Off SE point of Christmas Island	Airburst	2200	1.8 Mt
GRAPPLE Y Christmas Island	28 04 58 1905Z	Off SE point of Christmas Island	Airburst	2500	3.0 Mt
GRAPPLE Z	22 08 58 1800Z	Over SE point of Christmas Island	Balloon suspended	450	24 Kt
Christmas Island	02 09 58 1724Z	Off SE point of Christmas Island	Airburst	2800	1.0 Mt
	11 09 58 1748Z	Off SE point of Christmas Island	Airburst	2600	0.8 Mt
	23 09 58 1759Z	Over SE point of Christmas Island	Balloon suspended	450	25 Kt

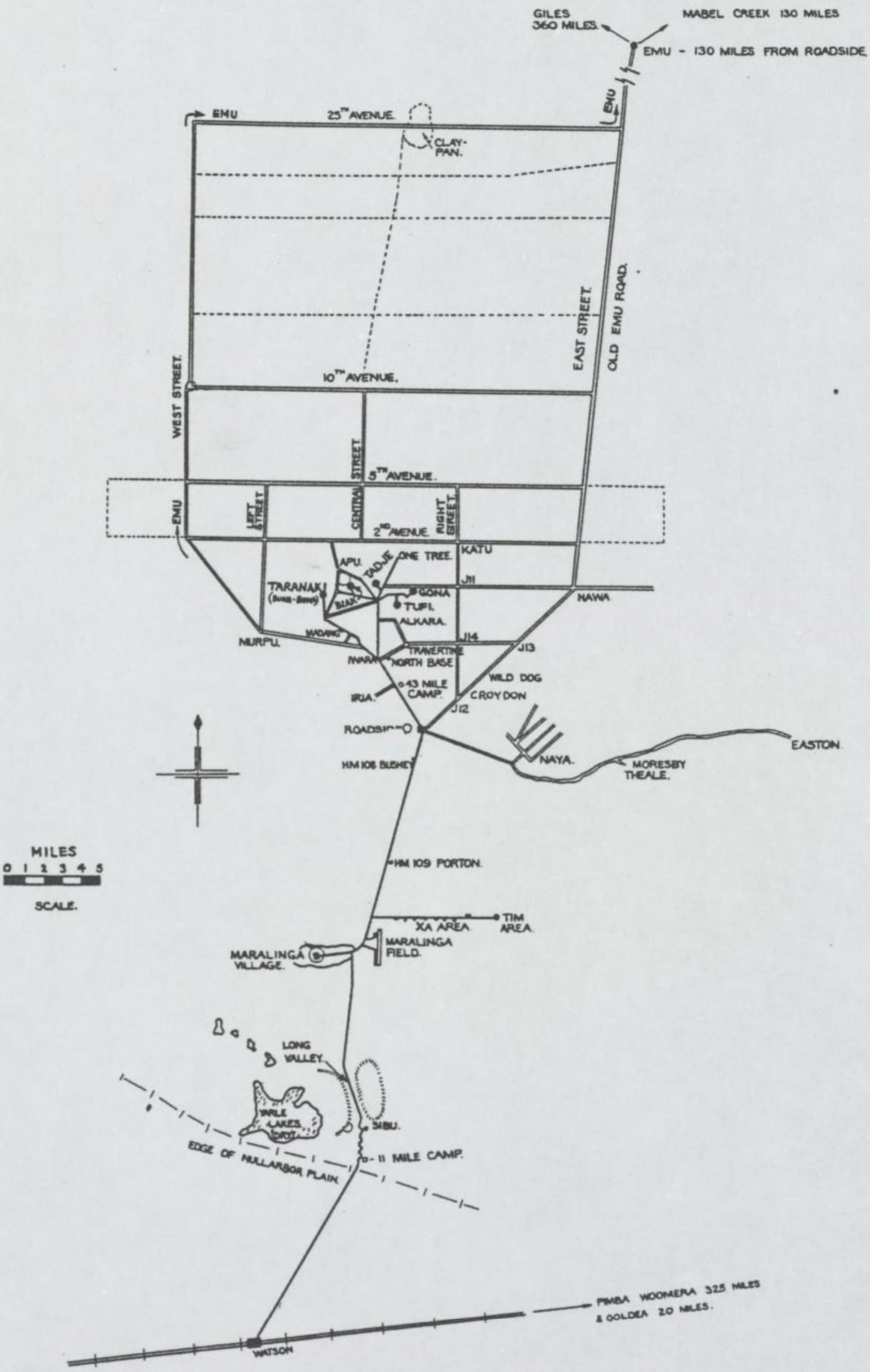
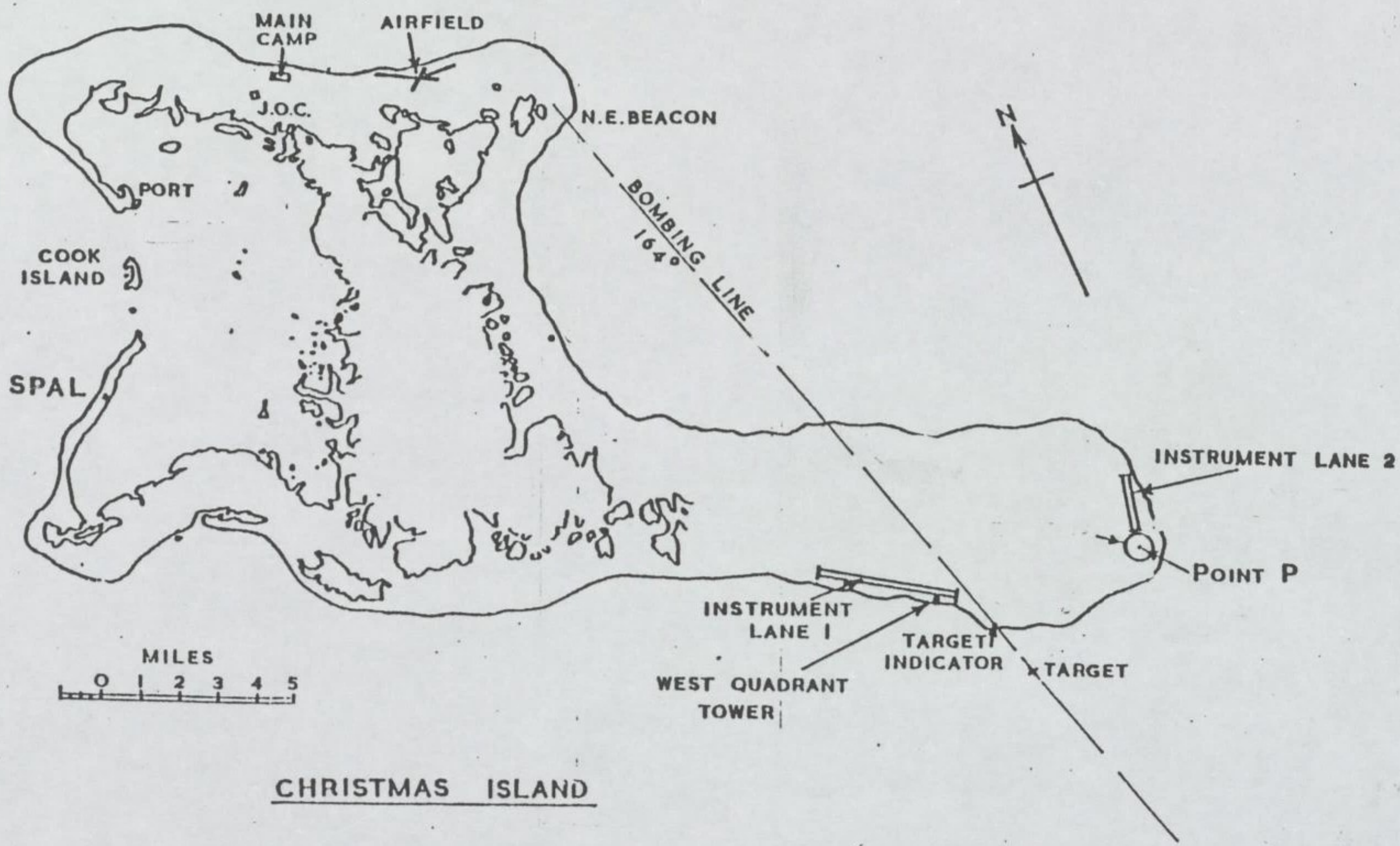


FIGURE 2

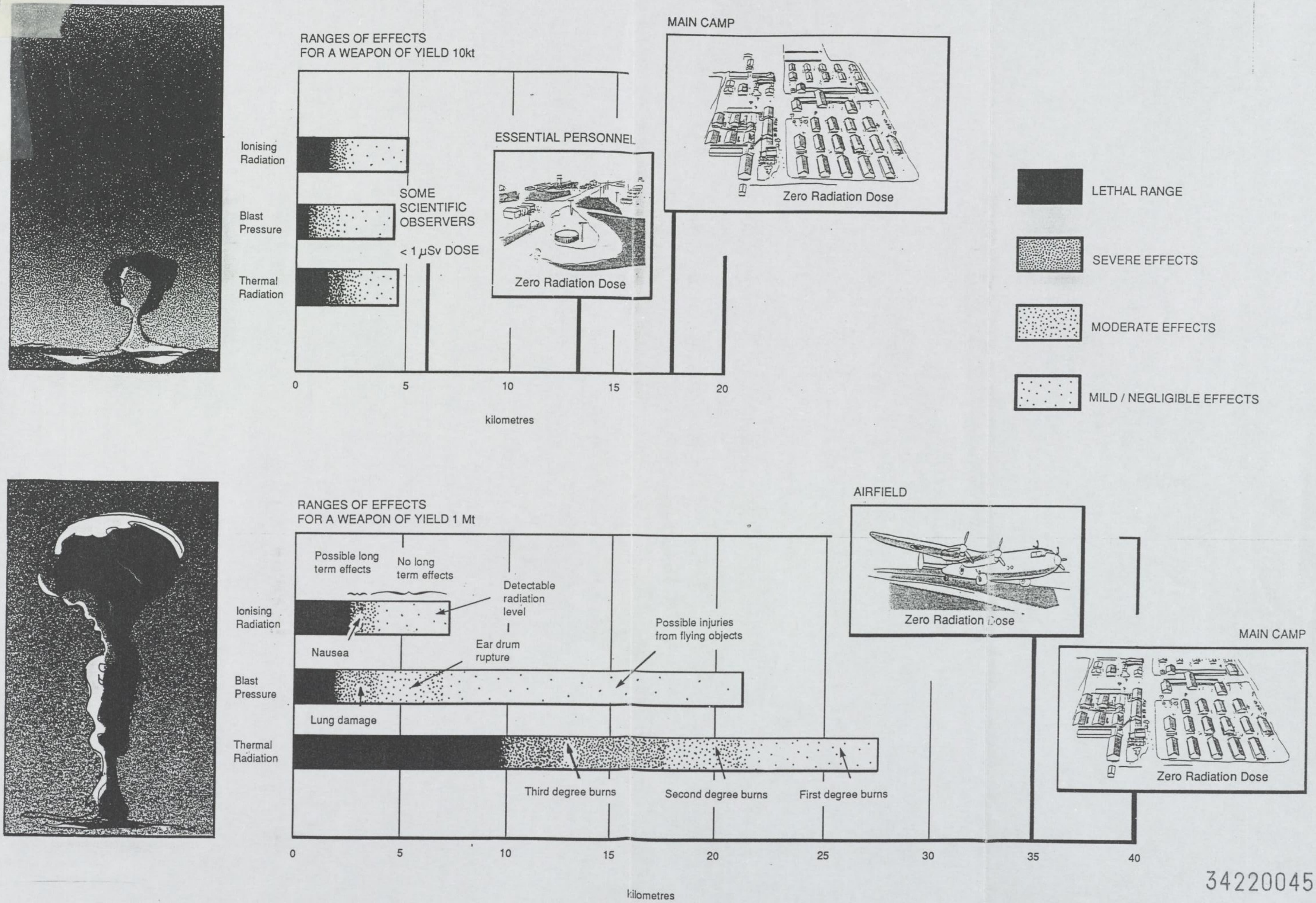
34220043



CHRISTMAS ISLAND

FIGURE 3

34220044



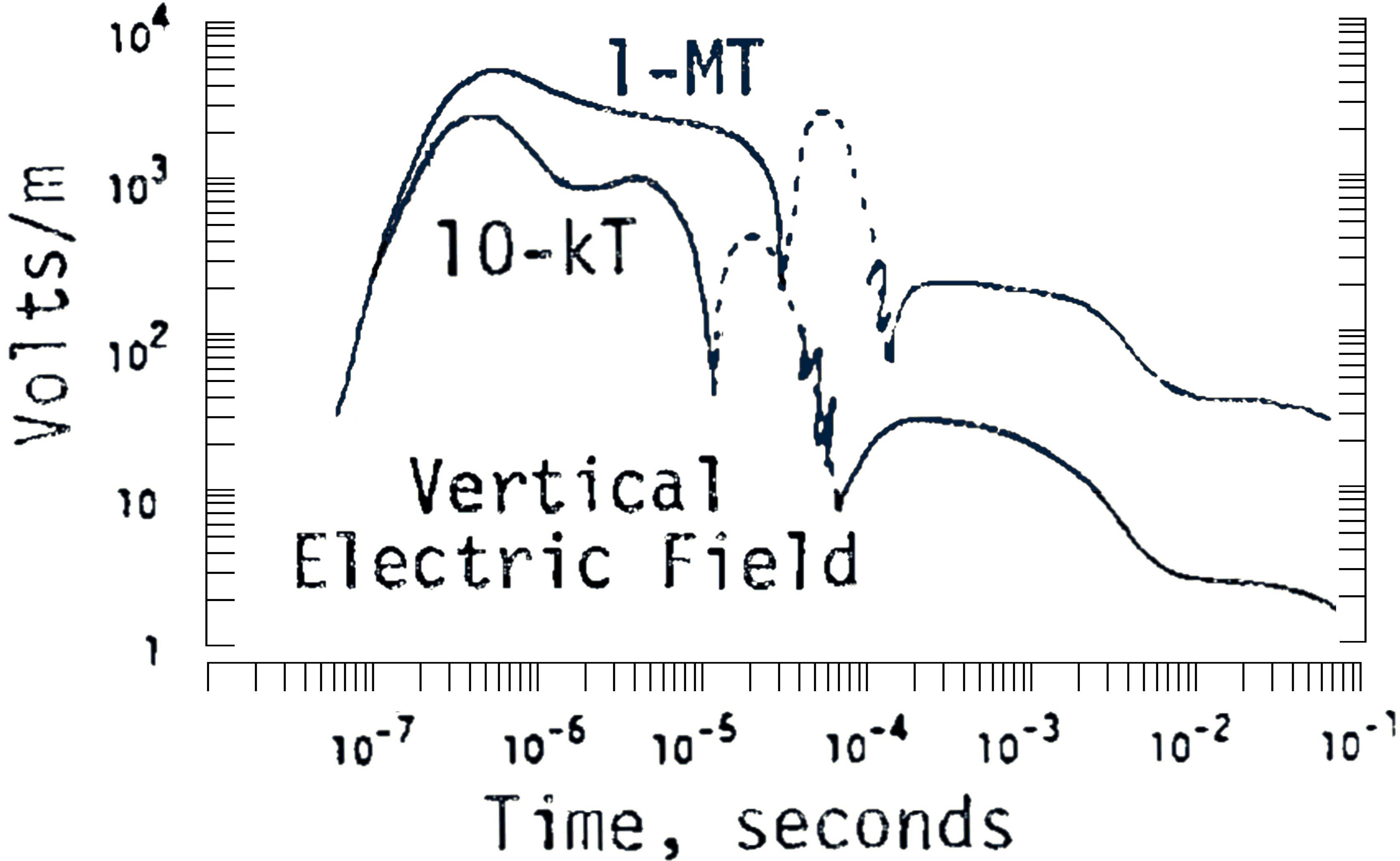
34220045

FIGURE 4

Effects of Nuclear Weapons on Unprotected Personnel

C. L. Longmire, "History and Physics of EMP," presentation at the Fourth NEM Symposium, Baltimore, Maryland, July 2, 1984.

10 km range from surface bursts (solid lines = negative fields; dashed lines = positive fields)



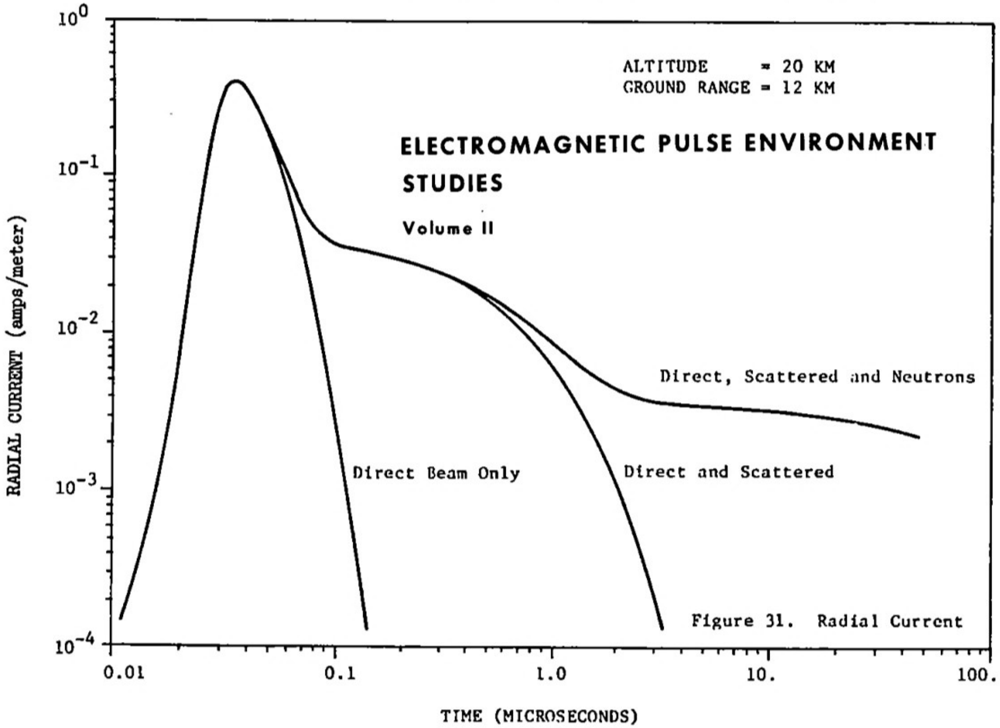


Figure 31. Radial Current

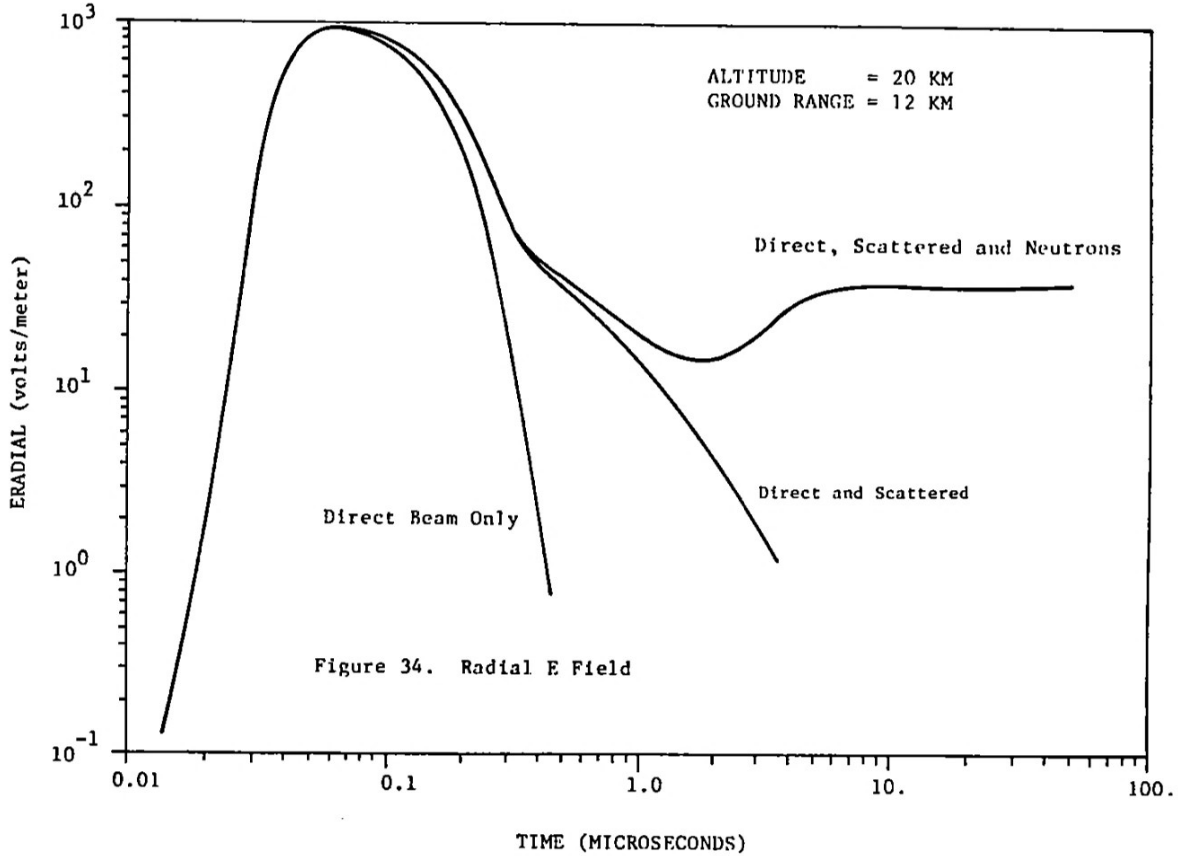


Figure 34. Radial E Field

3.53Mt, 15% fission
Redwing-Zuni
surface burst, 1956
at
Bikini Atoll

[redacted]

[redacted] (ZUNI)

Project 6.5 - Analysis of Electromagnetic Pulse Produced by a Nuclear Explosion - Charles J. Ong

OBJECTIVE

The objective of Project 6.5 is to obtain waveforms of the electromagnetic radiation for all the detonations during Operation REDWING. This data is to be used in connection with a continuing study relating the wave form parameters to the height and yield of the detonation.

INSTRUMENTATION

Two identical stations are used to record data, one at Eniwetok and one at Kwajalein.

The instrumentation consists of a wide-band receiver with separate outputs connected to each of the three oscilloscopes. Mounted on each oscilloscope is a Polariod Land Camera for recording the transient display.

RESULTS

Station A: Eniwetok

The predicted field strength [redacted] was 16.0 volts per meter. The measured field strength [redacted] was 14.4 volts per meter. The general waveform for the 1.0 μ sec/cm sweep was poor but the waveforms recorded for the other two scopes were good.

Station B: Kwajalein

No record data due to the loss of timing with WWVH.

CONCLUSIONS

All data has been forwarded to Evans Signal Laboratory for final analysis.

[redacted]

Chapter 10

TEST of SERVICE EQUIPMENT and MATERIALS

10.3 WAVE FORM OF ELECTROMAGNETIC PULSE FROM NUCLEAR DETONATIONS

The objective was to obtain and analyze the wave form of the electromagnetic (EM) pulse resulting from nuclear detonations. In particular, broad-band measurements were made from 0 to 10 Mc at ranges up to 460 miles.

Previous measurements of the EM pulse were made during Operations Crossroads, Sandstone, Greenhouse, Buster-Jangle, Tumbler-Snapper, Ivy, Upshot-Knothole, Castle, Teapot, and Redwing. The equipment used for these measurements ranged from narrow-band tuned receivers to broad-band untuned receivers. The antennas used with these receivers varied from simple probes to specially designed discones. Equipment similar to that used by Operation Hardtack Project 6.4 had been used during Operation Castle. In general, the EM-pulse energy was found to be predominantly in the low frequencies (approximately 10 to 20 kc), with measurable components at frequencies as high as 300 Mc. The duration of the EM pulse was found to be approximately 50 μsec, with an initial rise time as short as 10 μsec.

Two stations were used: Kusaie, 460 miles from Bikini and 420 miles from Eniwetok; and Wotho, 100 miles from Bikini and 240 miles from Eniwetok. . . .

Shot Yucca (see Figures 10.1 and 10.2). No data was recorded at Wotho for this shot because of technical photographic problems. Several camera shutters did not open. Trace intensity was, in general, too low for proper recording. Also, field strength at Kusaie indicated that deflection at Wotho would have been some five times the scope limits.

All scopes at Kusaie triggered, and the signal was recorded. The wave form was radically different from that expected. The initial pulse was positive, instead of the usual negative. The signal consisted mostly of high frequencies of the order of 4 Mc, instead of the primary lower-frequency component normally received (Figures 10.1 and 10.2). The fact that Shot Yucca was a very-high-altitude shot may have provided a more favorable propagation path for the higher frequencies that were recorded.

Shot Cactus (see Figures 10.3, 10.4 and 10.5). The signal from this shot was received and recorded at Wotho. A secondary positive spike appeared in the signal, even though a single-stage nuclear device was used (Figure 10.4).

TABLE 10.1 WAVE FORM AND SHOT PARAMETERS

Shot	Yield	Number of Stages	Range	Peak Negative Field Strength	Plateau Negative Field Strength
	kt		miles	v/m	v/m
WOTHO DATA:					
Cactus	17	Single	240	1.7	0.92
Fir	1,360	Two	100	6.4	2.6
Butternut	82	Two	240	2.8	1.3
Koa	1,370	Two	240	1.2	—
Holly	5.75	Single	240	1.2	0.82
Nutmeg	22.5	Two	100	8.0	2.9
KUSAIE DATA:					
Yucca	2.0	Single	440	0.45	
Butternut	82	Two	460	0.33	
Koa	1,370	Two	460	0.28	
Holly	5.75	Single	460	0.18	
Nutmeg	22.5	Two	440	0.54	

Hardtack ITR 1660 summary extracts

AD369152

Project 6.5 - Analysis of Electromagnetic Pulse Produced by Nuclear Explosion - C. J. Ong

Objective

The objective of Project 6.5 is to obtain waveforms of the electromagnetic radiation for all the detonations during Operation REDWING. This data is to be used in connection with a continuing study relating the waveform parameters to the height and yield of the detonation.

Instrumentation

Two identical stations are used to record data, one at Eniwetok and one at Kwajalein.

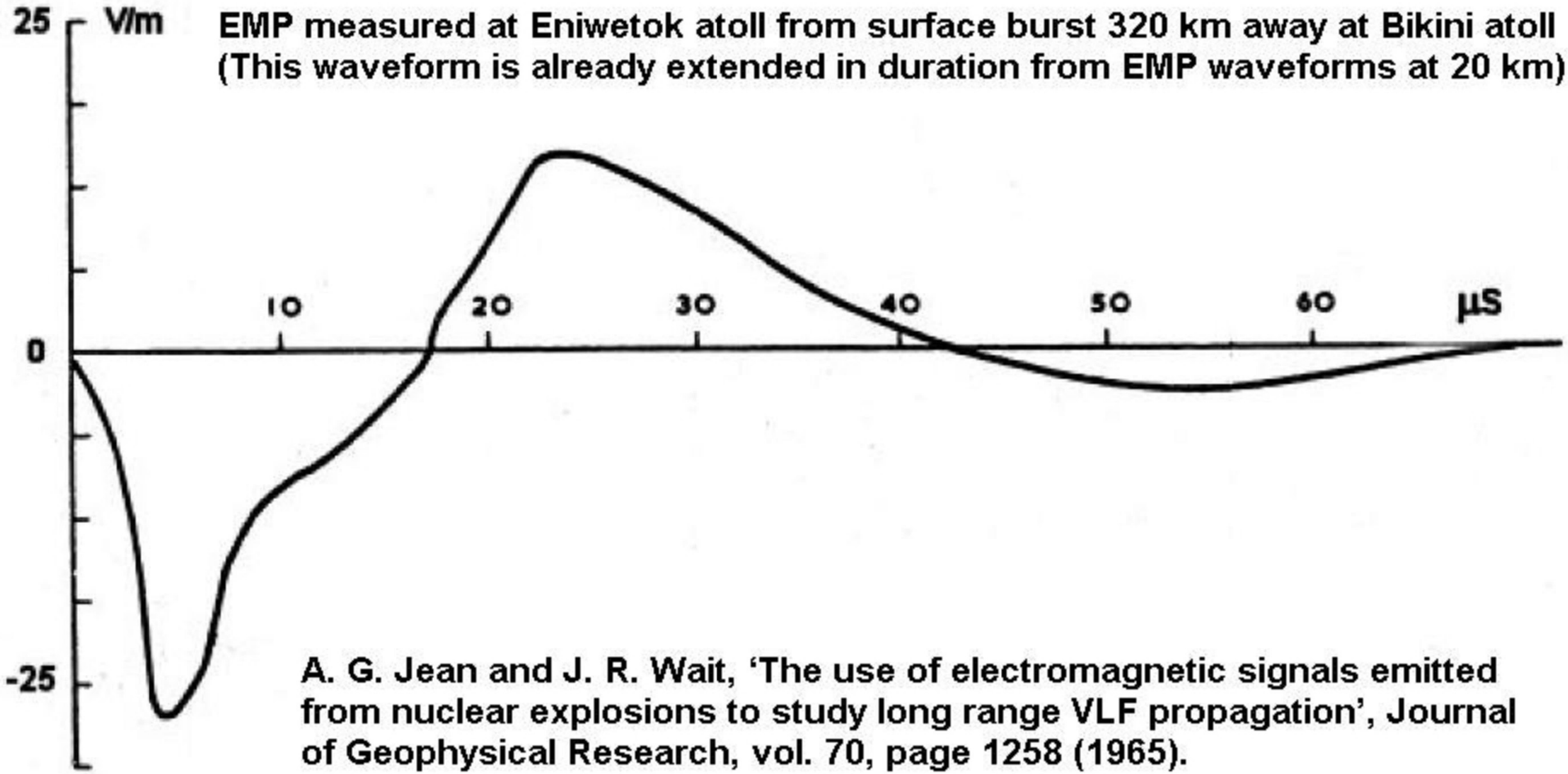
The instrumentation consists of a wide-band receiver with separate outputs connected to each of the three oscilloscopes. Mounted on each oscilloscope is a Polaroid Land Camera for recording the transient display.

The wide-band receiver consists of one primary and four secondary cathode follower amplifiers. An antenna, frequency insensitive in the range of interest is fed directly into the primary cathode follower. The primary cathode follower is then connected to four individual cathode followers by a 50-ohm coaxial cable. Only three secondary cathode followers are utilized, the fourth serving as a spare.

The number one and two cathode followers feed oscilloscopes with sweep speeds of approximately 30 micro-seconds per centimeter and 10 microseconds/centimeter respectively. The number three cathode follower is connected to the third oscilloscope through a 2 micro-second delay line. The third oscilloscope has a sweep speed of 1.0 micro-seconds/centimeter. All oscilloscopes were triggered simultaneously by the DC

[redacted]

EMP measured at Eniwetok atoll from surface burst 320 km away at Bikini atoll
(This waveform is already extended in duration from EMP waveforms at 20 km)



A. G. Jean and J. R. Wait, ‘The use of electromagnetic signals emitted from nuclear explosions to study long range VLF propagation’, Journal of Geophysical Research, vol. 70, page 1258 (1965).

[redacted]

trigger device located in the primary cathode follower and connected directly to the receiving antenna. The 2 micro-second delay line was added to permit the leading edge of the waveform to be recorded.

In order to establish a definite time relationship between the reception of the signal and the triggering of a given device such as a counter or transmitter, a time marker pip, generated by the delay trigger from one of the oscilloscopes, is fed through the 2 micro-second delay line and superimposed on the initial portion of the received waveform.

Procedure

All oscilloscopes are calibrated against a known frequency standard for sweep linearity.

The cathode follower triggering system is set to trigger approximately 6 db. above the noise level. The vertical deflector of the oscilloscopes are set to receive the predicted field strength.

Results

Station A - Parry Island

Waveform traces were obtained on two oscilloscope photos and the third oscilloscope failed to function properly. The predicted field strength was 43.0 volts per meter and the measured field strength was 17.0 volts per meter. The waveform traces are of good quality.

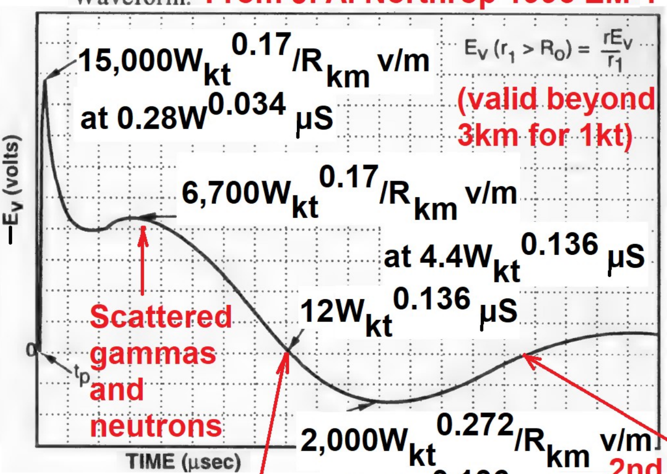
Station B - Kwajalein

Waveform traces were obtained on two oscilloscope photos and the third failed to trigger. The predicted field strength was 25.0 volts per meter and the measured field strength was 6.8 volts per meter.

[redacted]

68

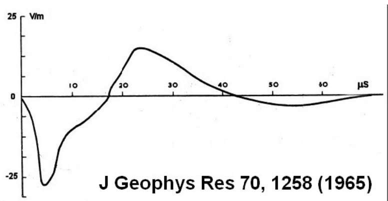
Figure 10.20. Generic Radiated Ground-Burst EMP Waveform. From J. A. Northrop 1996 EM-1



2nd crossover (from positive back to negative sign)

1st crossover (from negative to positive sign)

Eniwetok-Bikini 320 km

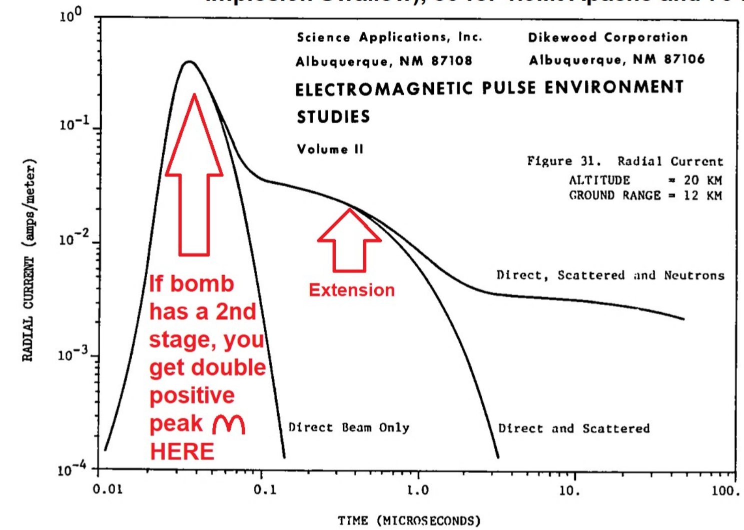


In a built-up city, steel framed and concrete buildings rapidly attenuate this EMP!

Left: at 320 km, the HF frequency peak of 0.3 µS has disappeared due to frequency dependent attenuation. The times to cross-over have also increased. At long distances, the times are extended by multipath distortion due the EMP being chanelled from bomb to target by multiple reflections between the conductive ocean surface and the ionosphere, which act as a waveguide in the same way that you can pipe microwaves through a waveguide consisting of a hollow metal tube from source to antenna.

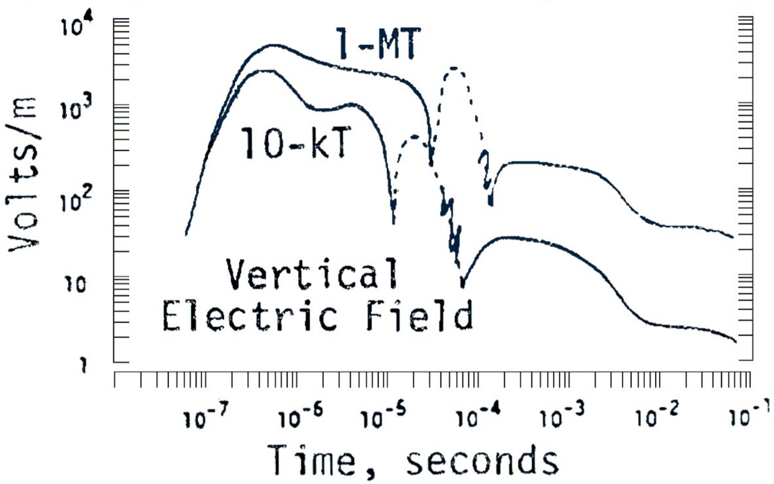
Table 7.2 in Redwing series weapon test report WT-1344 states that 2nd crossover occurred at 29 µS for 1.5kt Kickapoo (linear implosion Swallow), 50 for 1.9Mt Apache and 70 for 4.5Mt Navajo

AFWL-TR-73-286, Vol II



Logarithmic plot of surface burst EMP waveforms:

10 km range from surface bursts (solid lines = negative fields; dashed lines = positive fields)



C. L. Longmire, "History and Physics of EMP," presentation at the Fourth NEM Symposium, Baltimore, Maryland, July 2, 1984.

'The first attempt at a theory of [surface burst] radioflash was by [T.S.] Popham, in 1954, who suggested that radio signals were due to currents carried by Compton electrons arising from gamma rays produced in the nuclear explosion… Both the period and amplitude of the radio signal would be expected to increase very slightly with yield.'

- J.B. Taylor, A Theory of Radioflash, U.K. Atomic Weapons Research Establishment, report AWRE-O33/59, October 1959, Confidential, pp. 3-18.

Fig 1b by Taylor gives the EMP electric field from a ~1 kiloton surface burst (presumably the Marcoo 1.5 kt shot in 1956 at Maralinga): the peak field measured at a distance of 300 km is ~28.1 v/m in the NEGATIVE direction at a time of 5 microseconds. Zero field is at 17.2 microseconds. Peak positive is at 23 microseconds with ~15.4 v/m and second zero is at 42.5 microseconds. Second negative is at 54 microseconds with about ~ 3.75 v/m.

HENCE AT A DISTANCE OF 300 KM, FREQUENCY-DEPENDENT ATTENUATION INCREASES THE TIME SCALE OF THE FIRST FULL CYCLE OF THE RADIATED EMP FROM A SURFACE BURST BY A FACTOR OF TWENTY. HENCE THE PEAK FREQUENCY IS LOWER BY A FACTOR OF TWENTY AT 300 KM THAN IT IS AT 20 KM. Hence for a 1 kt surface burst, the peak close-in frequency of 1 MHz falls to just 50 kHz at 300 km.

For a nuclear weapon, the radius of the ionized region, **a**, **producing** the electromagnetic pulse was estimated from the relation

$$W = 4.55 \times 10^{-5}\ a \exp\left\{25\left[1-\exp(-0.1254a)\right]\right\} \quad (1.2)$$

Where: W = yield **Mt**

a = effective radius, kilometers.

$$E_{max} = \frac{3000\ a}{R}\left[1 - \frac{(a)^2}{R} + \frac{(a)^4}{R}\right]^{\frac{1}{2}} \quad (1.3)$$

Where: E_{max} = peak electric field, volts/meter

a = effective radius, feet

R = distance, feet

Low-frequency magnetic fields could not be predicted reliably. The maximum value for the high-frequency horizontal component was estimated from the equation:

$$H_\phi = \left[100\ \frac{W}{R^2}\ \exp.\ (-2.5R)\right]^{0.43} \quad (1.4)$$

Where: H_ϕ = horizontal component, oersteds

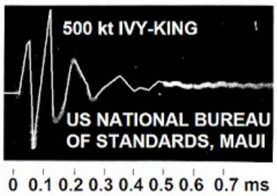
R = distance, kilometers

W = yield, **Mt**

ABOVE: surface burst EMP data from pages 16-17 of POR-2239 / weapon test report WT-2239, by P. J. Sykes, Jr., "Operation Sunbeam, Project Small Boy, Project Officers Report - Project 7.1.4, Transient Radiation Effects Measurements on Guidance Systems Circuits", DTIC AD-A995 378.

M. H. OLESON, "OPERATION IVY, PROJECT 7.1, REPORT TO THE SCIENTIFIC DIRECTOR, ELECTROMAGNETIC EFFECTS FROM NUCLEAR EXPLOSIONS," nuclear weapons test report WT-644, AD-A995 500:

FIGURE 15: EMP WAVEFORM FROM 500 KILOTON KING ENIWETOK TEST IN 1952, RECORDED AT MAUI.



Page 9: "During Ranger (Nevada, January-February, 1951) large excursions were noted on a Brush recorder attached to a long wire and crystal diode. Hastily-planned measurements, using oscilloscopes, during Greenhouse (Eniwetok, early Summer, 1951) demonstrated pulses with sharp rise times coincident with the detonation of the nuclear devices. In the Fall of 1951 (Nevada,Buster-Jangle) electromagnetic effects which could be fairly well correlated with the atomic explosions were reported by stations at varying distances from the detonation points."

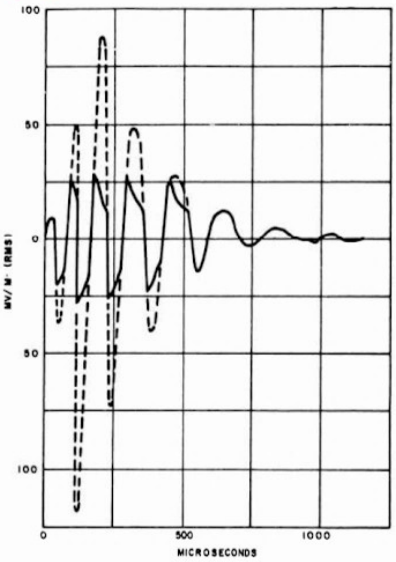
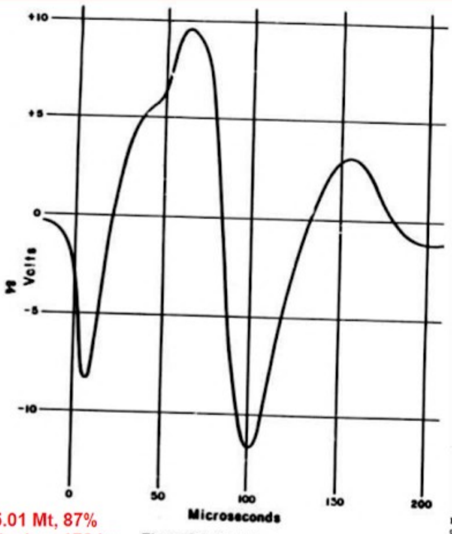


Figure 17 Shot King - National Bureau of Standards broad band wave form recorded at Stanford University. Dotted sections show probable shape.



5.01 Mt, 87% fission, 178 km

Figure 3.2 Shot Tewa

3.2.1 Shot Tewa. During Shot Tewa, the sixteenth of the seventeen Redwing test shots, the aircraft was 96 naut mi (178 km) south of the detonation, at the 18,000-foot altitude which was usual for the flights. The signals received on the two fiducial antennas were both shown in the dual-beam oscilloscope, Type 333. The amplified signal from the smaller fiducial antenna, mounted inside the aircraft on the window rack, was displayed on Channel A, while Channel B displayed the signal from the larger antenna, mounted outside the aircraft skin.

Operation Redwing, Nuclear Weapon test report WT-1352

AJ. Waters, OPERATION REDWING-PROJECT 6.4 AIRBORNE ANTENNAS

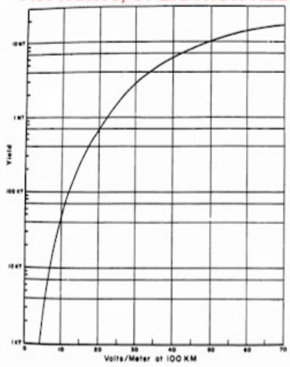


Figure 1.4 Empirical relation between detonation yield and the field strength of the electromagnetic pulse, referred to a range of 100 km (54 naut mi).

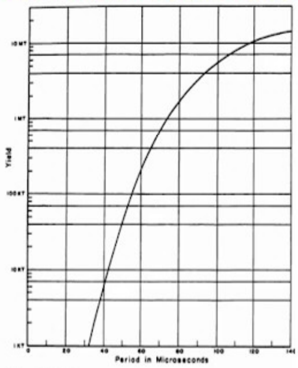


Figure 1.3 Empirical curve relating detonation yield and the period of the electromagnetic pulse.

EMP measured from the 5.01 megaton, 87% fission Redwing-Tewa surface burst, Bikini Atoll, 1956 (source: ADA995297)

A. Glenn Jean, "National Bureau of Standards, Preliminary Report on Castle, Project No. A/419/NBS", DTIC report AD0338553 (partially declassified in 2013):

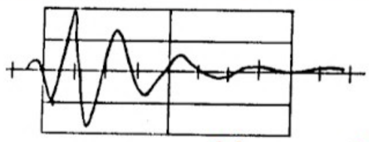


Fig. 11

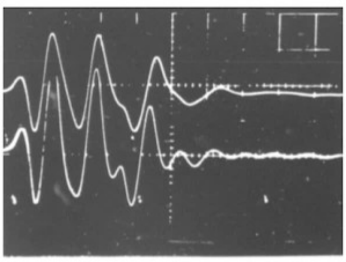
ROMEO
Maui, 4200 km path
Sweep rate 68 usec/cm
Sensitivity 0.98 v/m/cm

11 megatons Castle-Romeo surface burst

A. P. BRIDGES, ET AL., "OPERATION DOMINIC AND FISH BOWL SERIES, PROJECT OFFICERS REPORT - PROJECT 7.1, UNDERWATER EMP", POR-2033, weapon test report WT-2033, AD-A995 288, page 9:

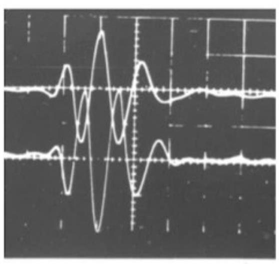
"The electromagnetic (EM) signal from a nuclear detonation has a waveform that has definite characteristics and is repeatable. It has been proposed to use this phenomena as the basis of a terminal surveillance system for use aboard the Polaris. "

Figure 3.37 Experimental signal, tape, Shot Bighorn.



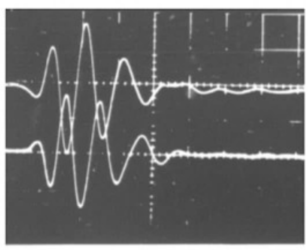
BIGHORN: USS LOYALTY
Upper-loop, lower-whip
Sweep speed, 0.1 msec/cm

Figure 3.33 Experimental signal, tape, Shot Rinconada.

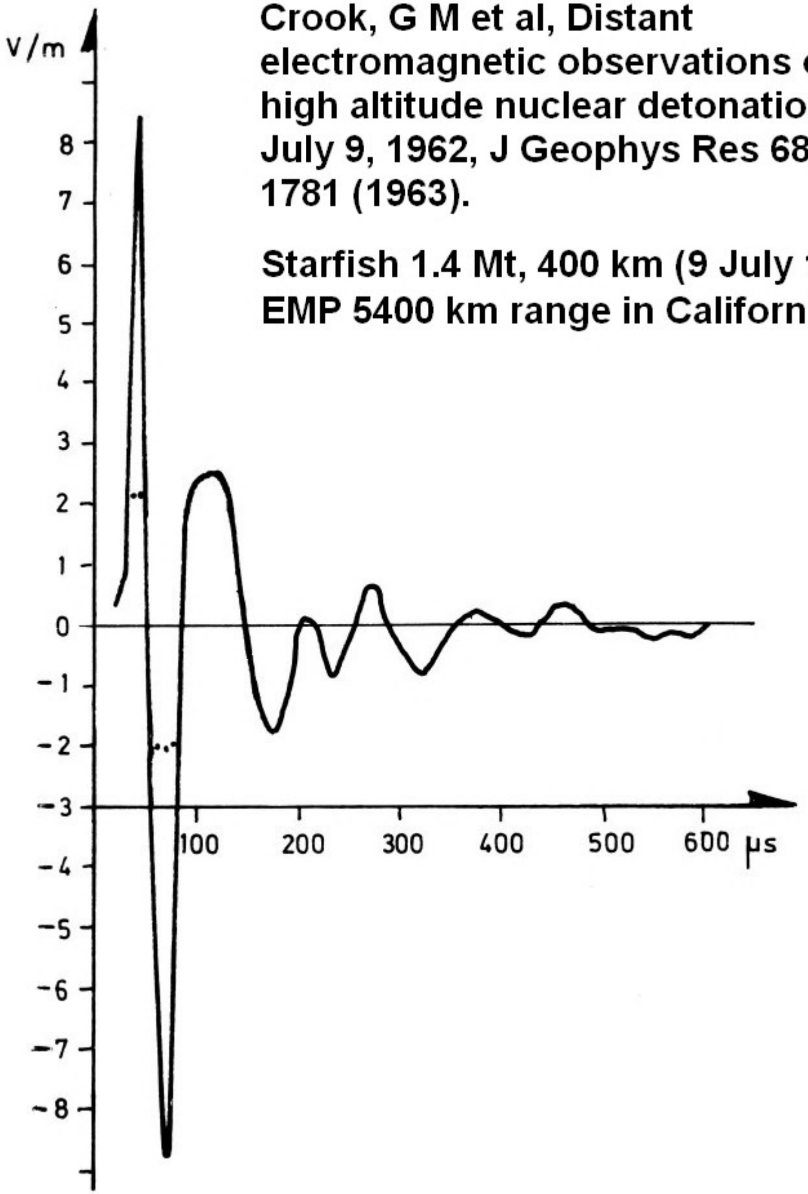


RINCONADA: USS LOYALTY
Upper-loop, lower-whip
Sweep speed, 0.1 msec/cm

Figure 3.32 Experimental signal, tape, Shot Harlem.

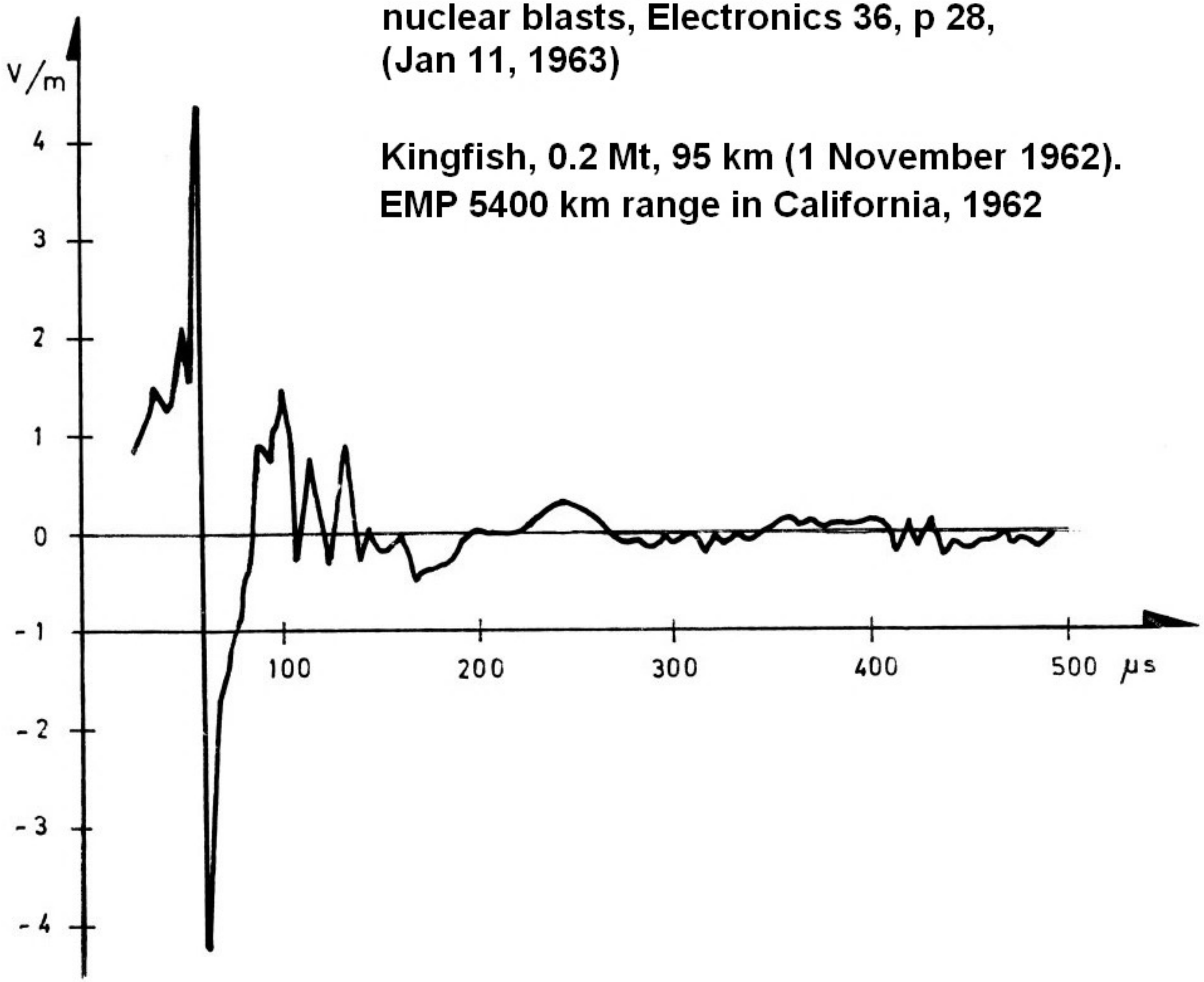


HARLEM: USS LOYALTY
Upper-loop, lower-whip
Sweep speed, 0.1 msec/cm



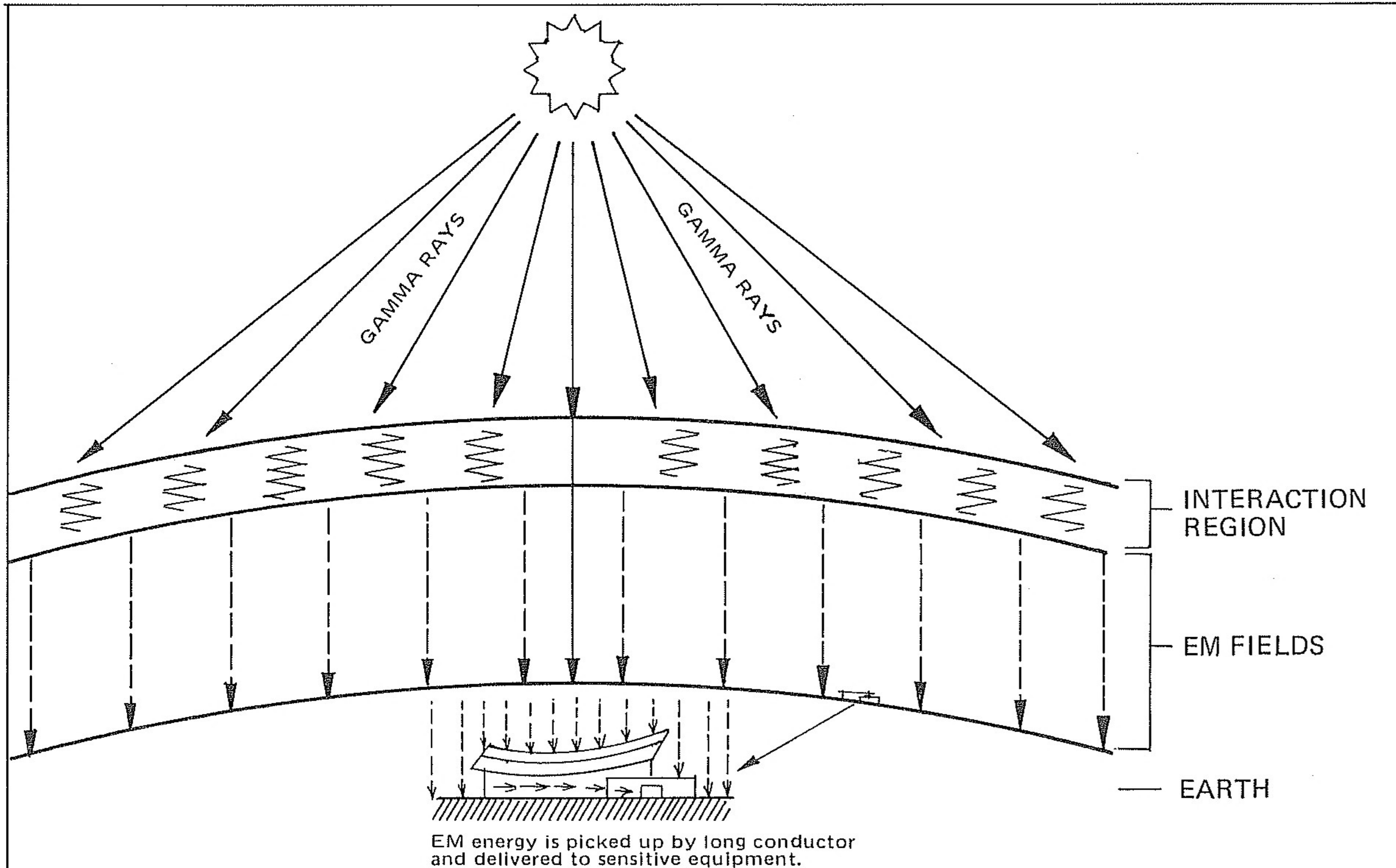
Crook, G M et al, Distant electromagnetic observations of the high altitude nuclear detonation of July 9, 1962, J Geophys Res 68, p 1781 (1963).

Starfish 1.4 Mt, 400 km (9 July 1962).
EMP 5400 km range in California, 1962



How radio can plot high altitude nuclear blasts, Electronics 36, p 28, (Jan 11, 1963)

Kingfish, 0.2 Mt, 95 km (1 November 1962).
EMP 5400 km range in California, 1962

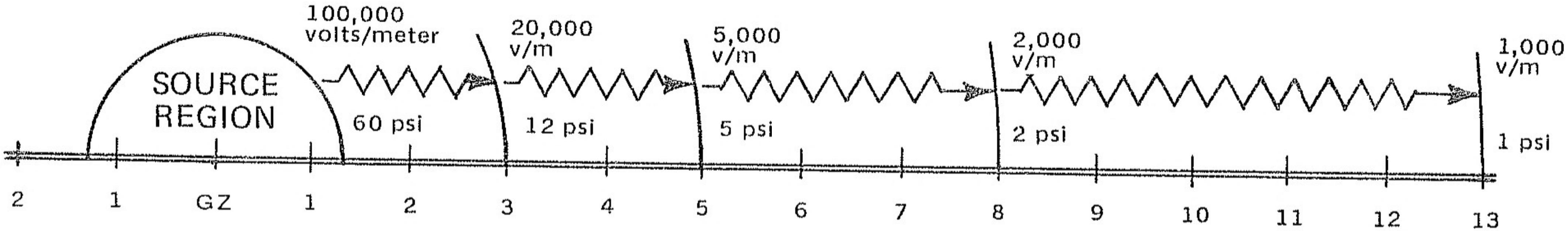


EMP ENERGY FROM HIGH ALTITUDE BURST.

Survive, November-December 1969.

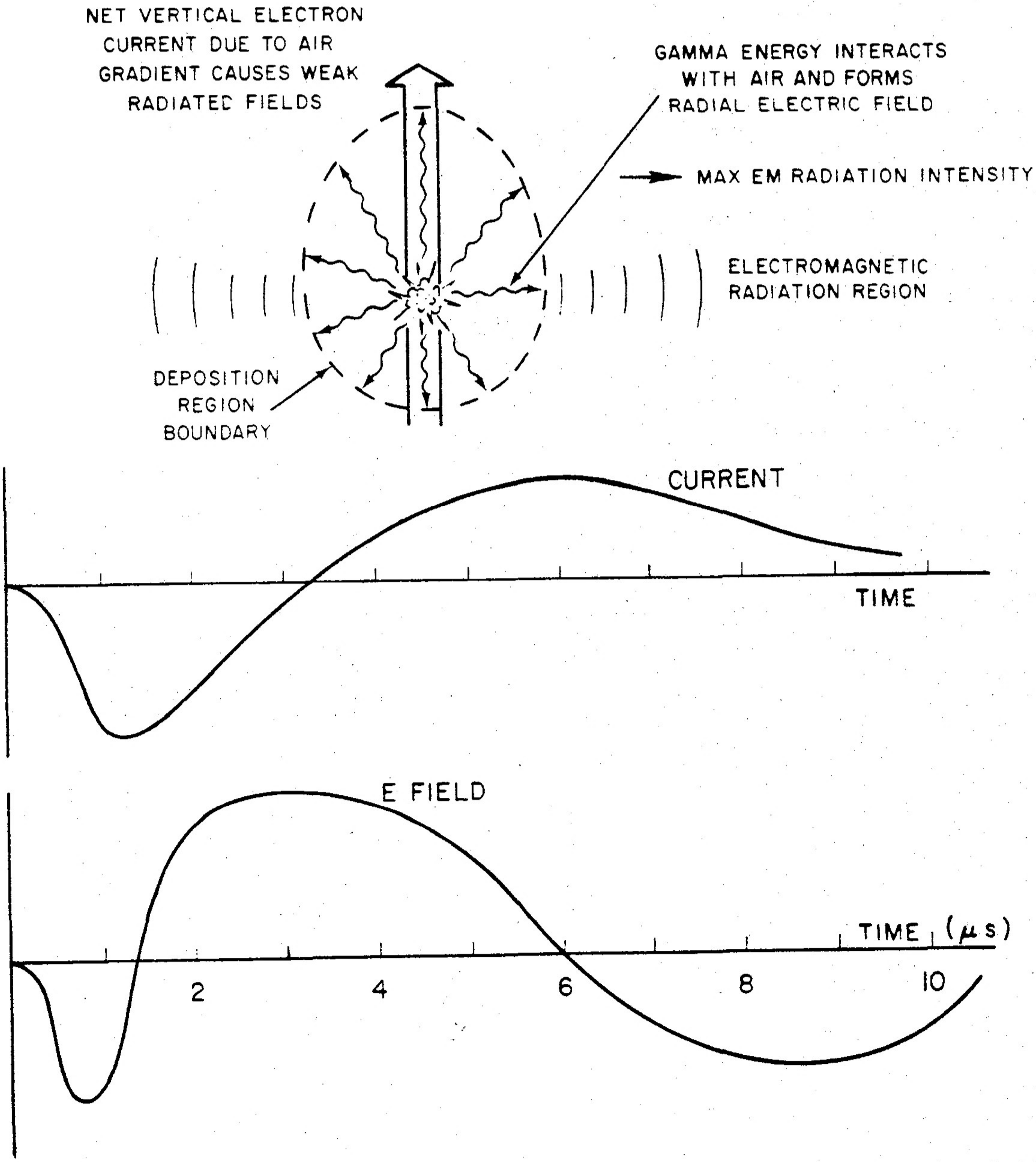
EMP FROM A 5–MT SURFACE BURST

SOURCE	INTENSITY (volts per meter)
EMP	UP TO 100,000
RADAR	200
RADIO COMMUNICATION	10



DISTANCE FROM GZ, MILES

Source: Defense Nuclear Agency



Comparison of General Waveforms for the Dipole Moment, the Current, and the E-Field for and Air Burst

WT-930 (EX)
EXTRACTED VERSION

OPERATION CASTLE

PROJECT 7.1

ELECTROMAGNETIC RADIATION CALIBRATION

PACIFIC PROVING GROUNDS

March - May 1954

M. H. Olseon

Headquarters Field Command
Armed Forces Special Weapons Project
Sandia Base, Albuquerque, New Mexico

June 13, 1958

NOTICE

This is an extract of WT-930, which remains classified SECRET/RESTRICTED DATA as of this date.

Extract version prepared for:

Director

Defense Nuclear Agency

Washington, D. C. 20305

31 August 1984

OBJECTIVES

In order to gain maximum information on nuclear detonations as determined from the electromagnetic pulse received at distances, there are two fundamental problems; first, the discrimination of nuclear-weapon pulses from natural atmospherics and second, the determination of the maximum information on the source itself and external conditions at detonation time, from the characteristics of the selected pulse. The 7.1 Castle project offered an opportunity to monitor detonations of nuclear devices of known composition and characteristics.

BACKGROUND

AFOAT-1 has supported experimental measurements of the pulse emitted at the time of a nuclear detonation during each series of atomic tests beginning with Buster-Jangle (Autumn, 1951). As a result of these experiments (References 1,2,3), the following can be stated with some assurance:

1. There is an electromagnetic pulse less than 100 μsec long emitted at the time of a nuclear detonation.
2. At a distance of 20 km from the generating source, the field strength may be a few hundred volts per meter.
3. There is a general relationship between kiloton yield and the vertical component of the electromagnetic field.
4. The emitted frequency spectrum extends from about 2 kc or below up to a few megacycles, but the main components are in the region of about 6 to 50 kc.
5. There is an approximate inverse relationship between yield and predominant frequency.
6. Pulses received close-in (i.e. approximately 20 km) exhibit very short rise times (less than a microsecond) in a negative direction (i.e. the electric field vector is downward).
7. The pulse is predominantly vertically polarised.
8. Close-in reception indicates that certain nuclear-weapon characteristics can be determined from pulse fine structure.
9. Even low-yield nuclear detonations can produce a pulse receivable at distances in excess of 1,000 km.
10. The ground wave is generally not detectable beyond about 1,500 km from the source because the ionospheric sky wave reflections predominate.
11. A fix of the source of the pulse can be obtained with direction-finding equipment; observed azimuthal errors to date using equipment tuned to 10 kc have been between 0 and 9 degrees; most errors have been less than 3 degrees.
12. At distances, the pulse is extended to approximately ten times its close-in length. This is the result of multiple arrivals by various paths, each characterized by one or more ionospheric reflection.
13. Close-in fine structure disappears during sky wave propagation to distances.

TABLE 1 SUMMARY OF CASTLE RESULTS

Station/Agency Distance (km) and calculated azimuths to Bikini (B) and Eniwetok (E)	Time as received at the station (Z), corrected for nuclear detonation pulse and WWV transmission times; Remarks; Recorded azimuths to detonation points; Field Strength data (v/m); a. Broad-band, center-to-peak (W whip, L loop); b. Narrow-band.	
	Shot 1 - 28 February 1954 - 1845:00.011Z Detonated at Bikini	Shot 2 - 26 March 1954 - 1830:00.378Z Detonated at Bikini
Eniwetok/NBS B 20 and 320 E 23	Radioactive debris fogged waveform equipment on Enyu Island, Bikini Atoll (20 km from detonation point).	1830:00.378 Waveform equipment was moved to Runit Island, Eniwetok for the balance of the series. a. ~ 21.0 (W)
Guam/NBS B 2,270 E 1,920	1845:00.011 a. 0.34 (W)	1830:00.378 a. 1.54 (W) b. 0.036 (8 kc) 0.042 (12.5 kc) 0.023 (20 kc)
Maui/NBS B 4,200 E 4,420	1845:00.010 a. 1.97 (W) b. 0.23 (8 kc) 0.26 (12.5 kc) 0.026 (20 kc)	No time record. a. 1.79 (W)
Shemya/DRL B 4,680; 209° E 4,750; 214°	Alert notification not received in time.	1830:00.376 a. 0.054 (L) 210° ±3°
Pt. Barrow/NBS B 7,280 E 7,360	Poor timing record. a. 0.52 (W)	1830:00.378 a. 0.61 (W) b. 0.010 (8 kc) 0.011 (12.5 kc) 0.00097 (20 kc)
Stanford Univ/NBS B 7,740 E 8,000	Not in operation.	1830:00.377 a. 0.42 (W) b. 0.020 (8 kc) 0.018 (12.5 kc) 0.0018 (20 kc)
Larson AFB/AF B 8,030; 267° E 8,200; 269°	Off scale. 270° ±3°	1830:00.5 * 271° ±3°
Boulder/NBS B 9,200 E 9,460	1845:00.012 a. 0.38 (W) b. 0.014 (8 kc) 0.16 (12.5 kc) 0.0015 (20 kc)	1830:00.379 a. 0.34 (W) b. 0.016 (12.5 kc) 0.0015 (20 kc)
Thule/DRL B 9,630; 307° ±1° E 9,700; 310° ±1°	Alert notification not received in time.	1830:00.378 a. ~ 0.02 (W) 310° ±3° 0.025 (L)
Duluth/AF B 10,080; 287° E 10,280; 289°	Not in operation.	Not in operation.
Austin/DRL B 10,100; 282° ±1° E 10,350; 284° ±1°	1845:00.011 a. 0.68 (W) 287° ±3° 0.083 (L)	1830:00.378 a. 1.10 (W) 0.13 (L)
Ft Belvoir/NBS B 11,530 E 11,750	1845:00.011 b. 0.006 (8 kc) 0.0044 (12.5 kc)	1830:00.378 a. 0.080 (W) b. 0.0054 (8 kc) 0.0052 (12.5 kc) 0.00078 (20 kc)
Andrews/AWS B 11,550; 296° E 11,770	Not in operation.	1830:00.32 * 300° ±3°
Dow AFB/AF B 11,750; 301° E 11,920	Equipment trouble.	1830:00.35 * 295° ±3°
W Palm Beach/AWS B 11,850; 291° E 12,070	1845:00.00 * 299° ±3°	1830:00.37 * 294° ±3°
Kirknewton/DRL B 12,510; 12° E 12,530; 17°	Alert notification not received in time.	Poor time correlation. 19° ±3° a. 0.049 (W)
Kindley AFB/AWS B 12,860; 302° E 13,100	1844:59.58 * 308° ±3°	Not in operation.

*Within limit of resolution.

ioscope and photographed.

<u>Local Timing</u>. Annex A of Reference 3 has a detailed account of the National Bureau of Standards (NBS) local timing unit. A typical time record from a close-in station is shown in Figure 1 and one from a

TABLE 1 SUMMARY OF CASTLE RESULTS (Cont)

Station/Agency Distance (km) and calculated azimuths to Bikini (B) and Eniwetok (E)	Time as received at the station (Z), corrected for nuclear detonation pulse and WWV transmission times; Remarks; Recorded azimuths to detonation points; Field Strength data (v/m); a. Broad-band, center-to-peak (W whip, L loop); b. Narrow-band.	
	Shot 3 - 6 April 1954 - 1820:00.411Z Detonated at Bikini	Shot 4 - 25 April 1954 - 1810:00.691Z Detonated at Bikini
Eniwetok/NBS B 20 and 320 E 23	1820:00.411 a. ~15.0 (W)	1810:00.691 a. ~40.0 (W)
Guam/NBS B 2,270 E 1,920	1820:00.412 a. 0.61 (W) b. 0.0034 (8 kc) 0.0065 (12.5 kc) 0.0080 (20 kc)	1810:00.692 a. 1.06 (W) b. 0.023 (8 kc) 0.043 (12.5 kc) 0.020 (20 kc)
Maui/NBS B 4,200 E 4,420	1820:00.412 a. 0.27 (W) b. 0.010 (8 kc) 0.013 (12.5 kc) 0.0013 (20 kc)	No time record. a. 1.49 (W)
Shemya/DRL B 4,680; 209° E 4,750; 214°	Alert notification not received in time.	1810:00.689 a. 0.039 (W) 214° ±3° 0.33 (L)
Pt. Barrow/NBS B 7,280 E 7,360	Poor time record. a. 0.046 (W) b. 0.0026 (8 kc) 0.0096 (12.5 kc) 0.0031 (20 kc)	No time record. a. 0.29 (W)
Stanford Univ/NBS B 7,740 E 8,000	1820:00.412 a. 0.048 (W) b. 0.0023 (8 kc) 0.0033 (12.5 kc) 0.0020 (20 kc)	1810:00.691 a. 0.33 (W) b. 0.0055 (8 kc) 0.0087 (12.5 kc) 0.0012 (20 kc)
Larson AFB/AF B 8,030; 267° E 8,200; 269°	Record not available.	Doubtful record.
Boulder/NBS B 9,200 E 9,460	1820:00.412 a. 0.055 (W) b. 0.0011 (8 kc) 0.0028 (12.5 kc) 0.00031 (20 kc)	1810:00.690 a. 0.33 (W) b. 0.0080 (8 kc) 0.018 (12.5 kc) 0.0011 (20 kc)
Thule/DRL B 9,630; 307° ±1° E 9,700; 310° ±1°	1820:00.411 a. 0.0035 (W) 314° ±3° 0.0012 (L)	1810:00.691 a. 0.046 (W) 307° ±3° 0.025 (L)
Duluth/AF B 10,080; 287° E 10,280; 289°	Not in operation.	Record not available.
Austin/DRL B 10,100; 282° ±1° E 10,350; 284° ±1°	1820:00.411 a. 0.027 (W) 285° ±3° 0.016 (L)	1810:00.691 a. 0.27 (W) 288° ±3° 0.12 (L)
Ft Belvoir/NBS B 11,530 E 11,750	1820:00.412 a. 0.016 (W) b. 0.00075 (8 kc) 0.001 (12.5 kc) 0.00022 (20 kc)	1810:00.690 a. 0.090 (W) b. 0.0021 (8 kc) 0.0055 (12.5 kc) 0.00062 (20 kc)
Andrews/AWS B 11,550; 296° E 11,770	Results negative.	1810:00.69 * 294° ±3°
Dow AFB/AF B 11,750; 301° E 11,920	Results negative.	Heavy sferics activity.
W Palm Beach/AWS B 11,850; 291° E 12,070	Started too late.	Not in operation.
Kirknewton/DRL B 12,510; 12° E 12,530; 17°	1820:00.411 a. 0.013 (W) 29° ±3° 0.003 (L)	1810:00.692 a. 0.0096 (W) 22° ±3° 0.0059 (L)
Kindley AFB/AWS B 12,860; 302° E 13,100	Not in operation.	Not in operation.

*Within limit of resolution.

...oscope and photographed.

Local Timing. Annex A of Reference 3 has a detailed account of the National Bureau of Standards (NBS) local timing unit. A typical time record from a close-in station is shown in Figure 1 and one from a

TABLE 1 SUMMARY OF CASTLE RESULTS (Cont)

Station/Agency Distance (km) and calculated azimuths to Bikini (B) and Eniwetok (E)	Time as received at the station (Z), corrected for nuclear detonation pulse and WWV transmission times; Remarks; Recorded azimuths to detonation points; Field Strength data (v/m); a. Broad-band, center-to-peak (W whip, L loop); b. Narrow-band.	
	Shot 5 - 4 May 1954 - 1810:00.156Z Detonated at Bikini	Shot 6 - 13 May 1954 - 1820:00.404Z Detonated at Eniwetok
Eniwetok/NBS B 20 and 320 E 23	1810:00.156 a. ~34.0 (W)	1820:00.404 a. ~775.0 (W)
Guam/NBS B 2,270 E 1,920	1810:00.154 a. 1.45 (W) b. 0.090 (8 kc) 0.047 (12.5 kc) 0.029 (20 kc)	1820:00.404 a. ~1.46 (W) b. 0.035 (8 kc) 0.028 (12.5 kc) 0.041 (20 kc)
Maui/NBS B 4,200 E 4,420	1810:00.156 a. 1.31 (W) b. 0.12 (8 kc) 0.056 (12.5 kc) 0.011 (20 kc)	1820:00.404 a. 1.44 (W)
Shemya/DRL B 4,680; 209° E 4,750; 214°	1810:00.155 a. 0.073 (W) 215° ±3° 0.42 (L)	1820:00.401 a. 0.037 (W) 210° ±3° 0.38 (L)
Pt Barrow/NBS B 7,280 E 7,360	1810:00.158 a. 0.35 (W) b. 0.013 (8 kc) 0.014 (12.5 kc) 0.0011 (20 kc)	No time record. b. 0.013 (8 kc) 0.014 (12.5 kc) 0.0011 (20 kc)
Stanford Univ/NBS B 7,740 E 8,000	No record	1820:00.405 a. 0.51 (W) b. 0.012 (8 kc) 0.019 (12.5 kc) 0.00097 (20 kc)
Larson AFB/AF B 8,030; 267° E 8,200; 269°	Poor signal	1820:00.3 * 272° ±3°
Boulder/NBS B 9,200 E 9,460	1810:00.158 b. 0.013 (8 kc) 0.014 (12.5 kc) 0.00057 (20 kc)	1820:00.405 a. 0.30 (W) b. 0.0068 (8 kc) 0.017 (12.5 kc) 0.0017 (20 kc)
Thule/DRL B 9,630; 307° ±1° E 9,700; 310° ±1°	1810:00.157 a. 0.041 (W) 308° ±3° 0.032 (L)	1820:00.404 a. 0.071 (W) 310° ±3° 0.028 (L)
Duluth/AF B 10,080; 287° E 10,280; 289°	1810:00.17 * 288° ±3°	1820:00.3 * 288° ±3°
Austin/DRL B 10,100; 282° ±1° E 10,350; 284° ±1°	1810:00.158 a. 0.259 (W) 286° ±3° 0.14 (L)	1820:00.405 a. 0.24 (W) 291° ±3° 0.13 (L)
Ft Belvoir/NBS B 11,530 E 11,750	1810:00.158 a. 0.070 (W) b. 0.0037 (8 kc) 0.0040 (12.5 kc) 0.00031 (20 kc)	1820:00.405 a. 0.078 (W) b. 0.0020 (8 kc) 0.0056 (12.5 kc) 0.00084 (20 kc)
Andrews/AWS B 11,550; 296° E 11,770	1810:00.17 * 298° ±3°	Not in operation.
Dow AFB/AF B 11,750; 301° E 11,920	Record not available.	1820:00.2 *
W Palm Beach/AWS B 11,850; 291° E 12,070	1810:00.14 * 292° ±3°	Not in operation.
Kirknewton/DRL B 12,510; 12° E 12,530; 17°	1810:00.158 a. 0.0086 (W) 26° ±3° 0.0063 (L)	1820:00.404 a. 0.012 (W) 21° ±3° 0.0070 (L)
Kindley AFB/AWS B 12,860; 302° E 13,100	1810:00.18 * 306° ±3°	Not in operation.

*Within limit of resolution.

loscope and photographed.

Local Timing. Annex A of Reference 3 has a detailed account of the National Bureau of Standards (NBS) local timing unit. A typical time record from a close-in station is shown in Figure 1 and one from a

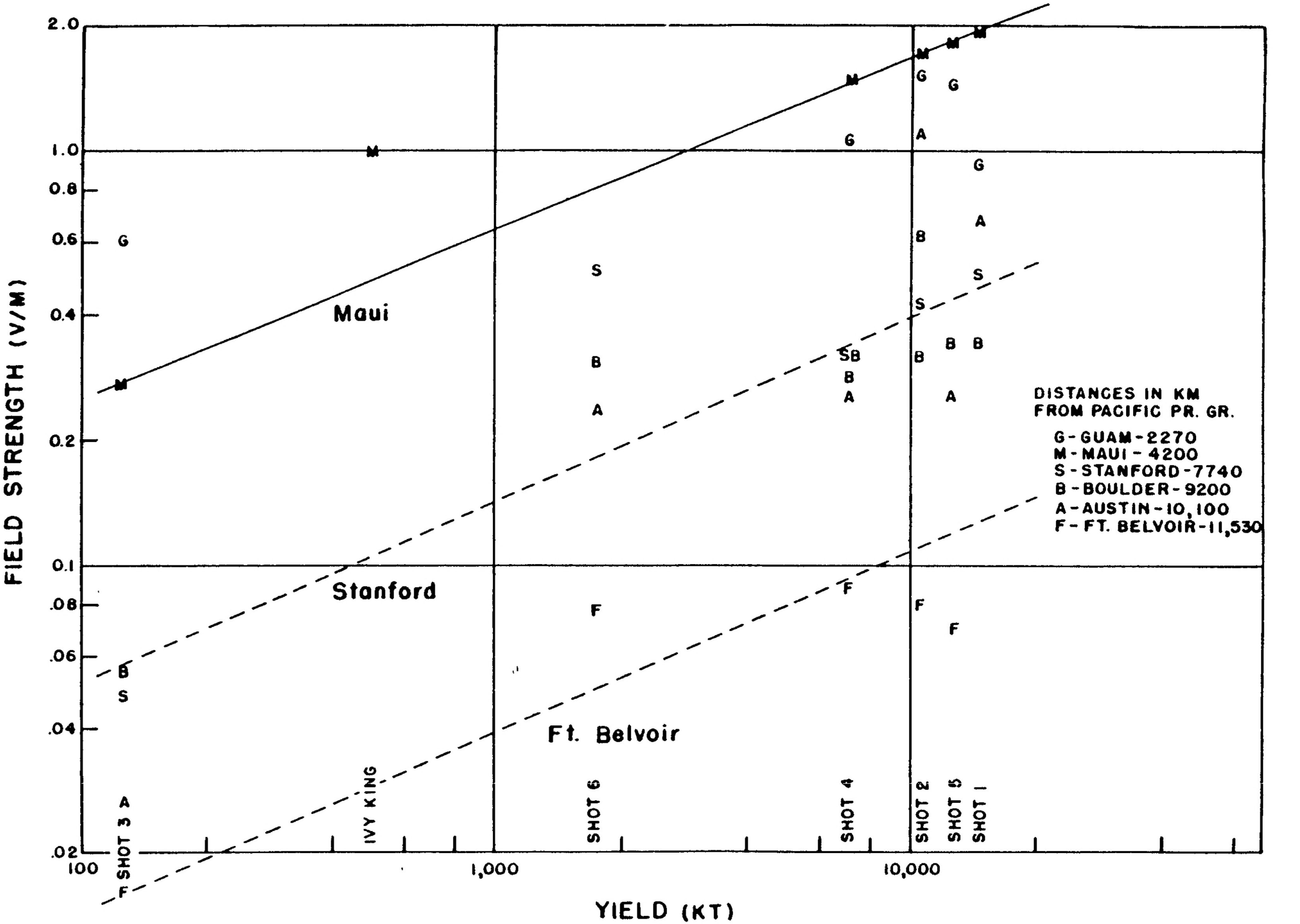


Figure 5 Plot of selected Castle data showing the relationship between peak field strength and yield on an east-west path. Probable curves, drawn by inspection, are shown for Maui, Stanford University and Ft. Belvoir.

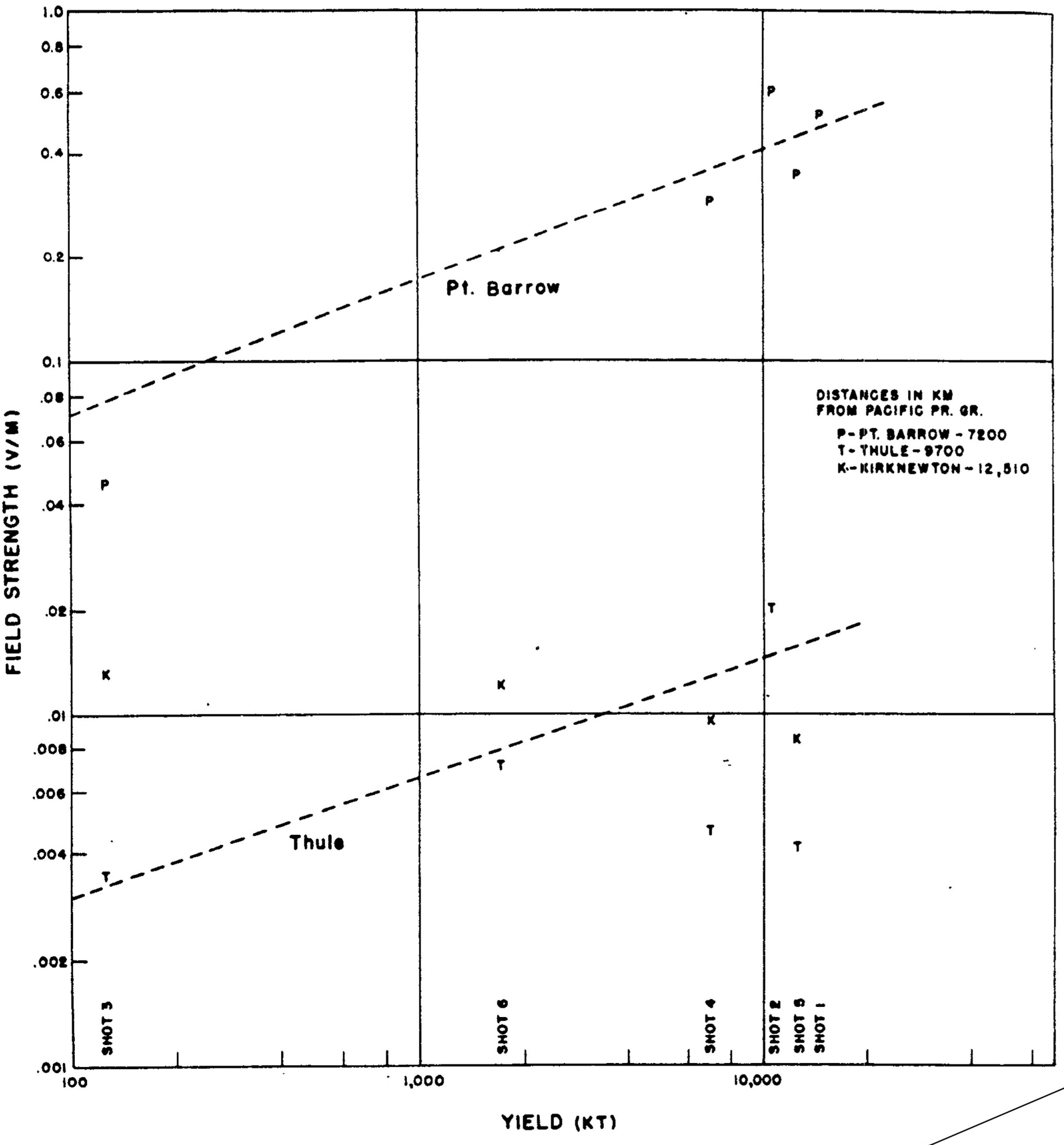
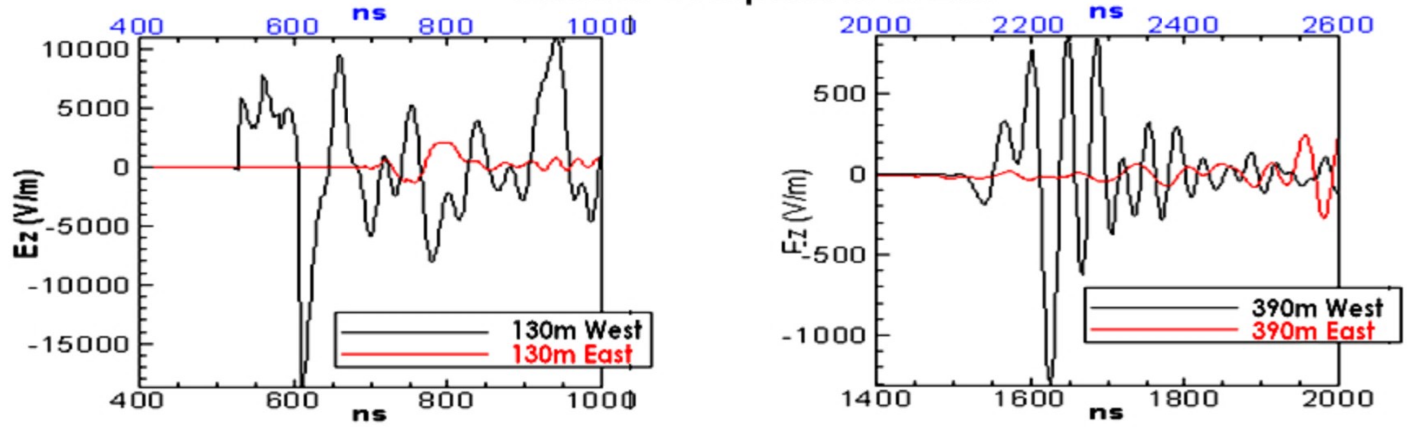


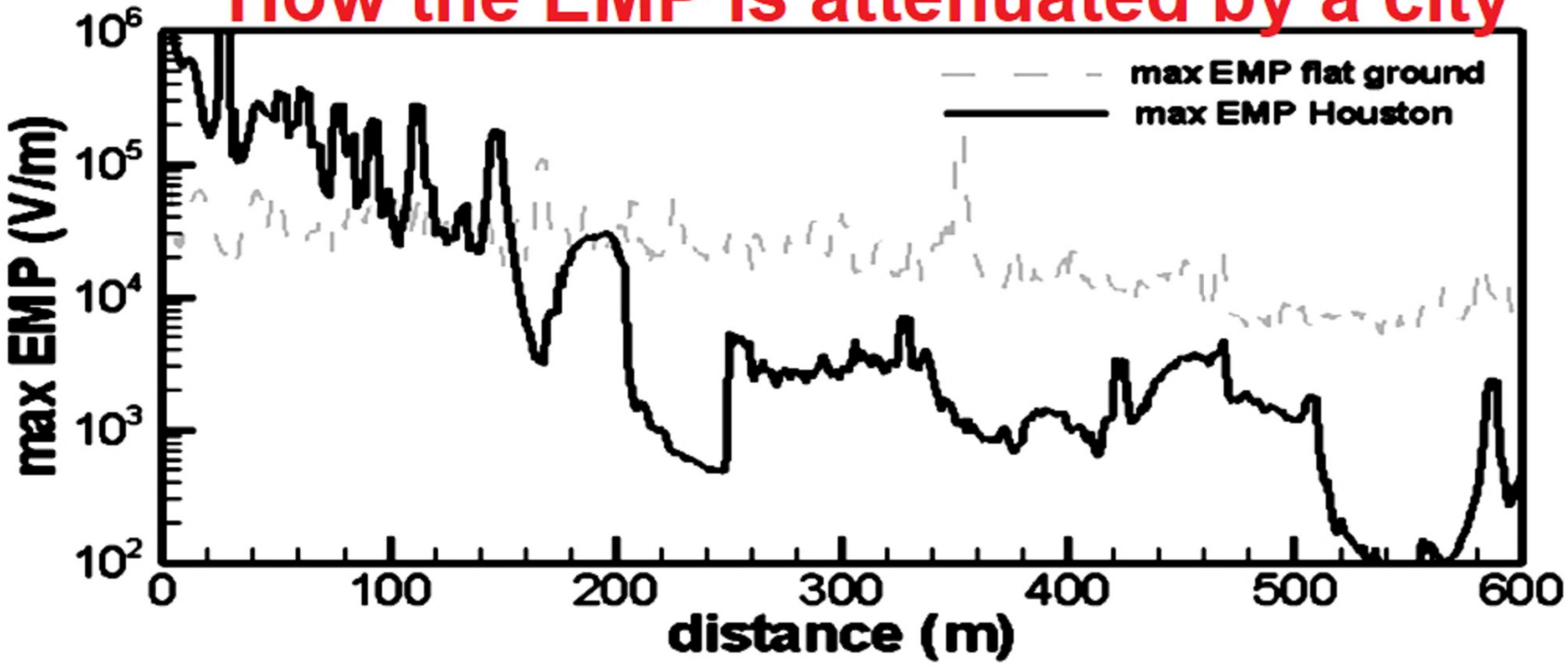
Figure 6 Plot of selected Castle data showing the relationship between peak field strength and yield on a north-south path. Probable curves, drawn by inspection, are shown for Pt. Barrow and Thule.

Vertical component of EMP



William S. Smith, et al., Nuclear EMP simulation for large-scale urban environments, Los Alamos, LA-UR-12-20227, 2012

How the EMP is attenuated by a city



Effects of buildings on maximum EMP from a generic "Fatman" type bomb in downtown Houston, Texas

Tall buildings (1) attenuate horizontal prompt gamma rays, (2) attenuate the line-of-sight (UHF) EMP frequencies

Scott Smith, Jeff Bull, Trevor Wilcox, Randy Bos, Xuan-Min Shao, Tim Goorley, Keeley Costigan

Nuclear EMP simulation for large-scale urban environments, Los Alamos LA-UR-12-24078, August 2012